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BEHAVIOUR OF IRON CHELATES IN CALCAREOUS SOILS

II. LABORATORY EXPERIMENTS WITH SOME FURTHER CHELATING AGENTS

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INTRODUCTION

The control of lime-induced iron chlorosis in fruit trees by soil application of the iron chelates Fe-EDTA and Fe-HEEDTA was reported in 1953 by Leonard and Stewart¹⁰, but it was found that large amounts were often needed and the results were sometimes irregular. Other chelating agents that have since become available for this purpose include diethylenetriaminepenta-acetic acid (DTPA), *cyclo*-hexane 1,2 diaminotetra-acetic acid (CDTA), N, N'-dihydroxyethylethylenediaminediacetic acid, (HEEDDA) and ethylenediamine N, N' bis (*ortho* hydroxyphenylacetic acid), (EDHPA, often referred to by the trade name Chel 138). Soil applications of the iron complexes of these four reagents have been used with varying success by several workers in attempts to control lime-induced chlorosis^{1 4 9 13 18}.

The laboratory experiments described below are a continuation of the work already published on Fe-EDTA and Fe-HEEDTA⁶, using the four other iron chelates mentioned above. The experiments were designed to give a direct comparison between the abilities of the iron chelates to remain in a soluble form in the presence of a highly calcareous clay, and to provide an explanation for the effectiveness, or otherwise, of these compounds in the field. The iron-chelate solutions applied to the soil were again labelled with Fe⁵⁹ in order to assess the extent to which this isotope was exchanged with soil iron and hence the reliability of results obtained by radio-assay alone.

EXPERIMENTAL

Much of the detail of the materials and experimental method has been given in the previous paper ⁶; only brief descriptions are given below unless the procedure has been altered.

1. *Soil*

This was an Evesham soil containing 28% calcium carbonate and 35% clay; its pH was 7.8.

2. *Preparation of labelled chelate solution*

This was done by mixing equimolar quantities of the chelating agents and ferric-chloride solutions labelled with Fe⁵⁹. Before use the excess acidity was neutralized with sodium hydroxide.

3. *Treatments*

Experiment 1. 50-g samples of the soil were prepared and to each was given one of the following nine treatments in triplicate: -

Treatment	Chelating agent	Quantity chelated iron (approx.)	Treatment	Chelating agent	Quantity chelated iron (approx.)
(1a)	DTPA	0.5 mg	(1e)	HEEDDA	0.5 mg
(1b)	"	5.0	(1f)	"	5.0
(1c)	CDTA	0.5	(1g)	EDHPA	0.5
(1d)	"	5.0	(1h)	"	5.0
Treatment (1i) — Water only.					

0.25 μ c Fe⁵⁹ was included in the 20 ml of iron-chelate solution applied as treatments (1a) — (1h). The exact amounts of chelate added to the soil are given below in the tables as the analytical results after 0 days. These amounts of labelled chelate corresponded to treatment levels of approximately 10 and 100 parts of chelated iron per million of soil.

Until required for extraction, the treated soils were stored at a temperature of approximately 20°C in the dark in glass jars with loose cardboard covers. After each of six time intervals, (1, 2, 4, 8, 15 and 30 days, respectively), the three replicates of treatments *a*, *b*, *c*, *d* and *i* were extracted with water (see below). The replicates of treatments *e*, *f*, *g* and *h* were extracted after only the four intervals 2, 4, 8 and 15 days.

Experiment 2. Results obtained in the first experiment showed

that with Fe-DTPA there were large differences in the percentage recoveries of iron at the two treatment levels, 10 and 100 ppm Fe. With Fe-CDTA and Fe-EDHPA, however, the percentage recoveries were high and independent of the amount applied. Further investigations were made, therefore, to ascertain the influence of rate of application of these four iron chelates on the percentage recovery.

50-g samples of soil were treated with 20 ml of solution containing the appropriate amount of chelated iron to give the following treatment levels: -

(2a) Fe-DTPA	at approximately 50, 25 and 5 ppm, ($\mu\text{g Fe/g soil}$)
(2b) Fe-CDTA	„ „ 50, 5 and 2.5 ppm
(2c) Fe-HEEDDA	„ „ 50 and 5 ppm
(2d) Fe-EDHPA	„ „ 5 and 2.5 ppm

No radioactive iron was used in this experiment. Three replicates of each treatment were extracted with water after 4 and 15 days storage.

4. Extraction procedure

The treated soil samples were shaken with 100 ml water until equilibrium was reached then a clear extract was obtained by centrifugation.

5. Methods of analysis

a. Soluble iron

(i) Isotope method. The values for soluble iron by the isotope method given in Table I are the amounts of iron that were originally associated with the radioactivity found in the leachate.

(ii) Colorimetric method. The concentration of iron was determined by the *o*-phenanthroline method of Fortune and Mellon³. The modifications proposed by Wallace *et al.*¹⁶ to overcome the presence of the chelating agents CDTA, DTPA and EDHPA were used, except that with Fe-CDTA it was found unnecessary to adjust the pH of the solution to 9 before heating. The presence of HEEDDA was found not to affect the development of full colour with *o*-phenanthroline after standing for 1 hour with the reagents.

(iii) Spectrophotometric method. The chelated-iron concentration was determined by a spectrophotometric method, using the conditions proposed by Hill-Cottingham^{5 8}. It was again assumed that, of the other metal chelates present in these soil extracts, calcium would predominate. The absorbance due to these calcium chelates, at the wavelengths used in this method for iron, was found to be negligible.

b. 'Total chelate'

The concentration of calcium chelate in the extracts was determined as

its equivalent of iron chelate by a spectrophotometric method as described previously^{6,7}. In this method the increase in chelated-iron concentration on addition of excess ferric ions is proportional to the concentration of calcium chelate in the original solution. The values given for 'total chelate' in Tables I and II are the sum of the iron equivalent of the chelated calcium and of the iron-chelate figures in the adjoining columns.

6. Presentation of results

As before, the results given in the tables have been adjusted to allow for the solution left in contact with the soil after decanting the clear centrifugate by multiplying the values obtained for the 100 ml of extract by 1.2.

TABLE I

Chelate content of soil extracts. Experiment 1. Mean of 3 replicates, expressed in $\mu\text{g Fe}$. ('Total chelate' values in equivalent of iron.)

Iron chelate	Time of contact (days)	Treatment							
		0.5 mg chelated iron (10 ppm Fe)				5.0 mg chelated iron (100 ppm Fe)			
		Soluble iron			Total chelate	Soluble iron			Total chelate
		Isotope method	Colorimetric method	Spectrophotometric method		Isotope method	Colorimetric method	Spectrophotometric method	
Fe-DTPA	0	521	521	504	504	5060	5060	4900	4900
	1	80	104	116	295	2260	2450	2400	2880
	2	65	89	115	306	1980	2170	2220	3180
	4	44	73	99	301	1720	2010	2050	3060
	8	21	35	62	281	1400	1800	1890	2880
	15	14	31	62	307	1190	1550	1740	2910
	30	8	22	60	295	1030	1570	1690	2460
Fe-CDTA	0	497	497	490	490	5440	5440	5390	5390
	1	457	440	436	438	4970	4780	4540	4540
	2	452	431	437	452	5040	4650	4670	4670
	4	440	424	425	462	5000	4730	4600	4600
	8	414	413	409	428	4720	4530	4380	4440
	15	403	400	395	428	4700	4370	4400	4520
	30	373	392	384	384	4530	4260	4120	4120
Fe-HEEDDA	0	392	392	396	396	4700	4700	4580	4580
	2	50	70	78	125	1070	1250	1250	1720
	4	33	59	96	146	890	1100	1270	1810
	8	26	69	83	172	830	1060	1080	1410
	15	20	70	96	161	740	1030	1000	1410
Fe-EDHPA	0	470	470	484	490	5200	5200	5200	5400
	2	431	439	442	446	4750	4880	4940	5000
	4	419	428	426	461	4660	4760	4790	4880
	8	413	443	415	472	4510	4750	4760	4950
	15	398	404	409	409	4460	4720	4720	4720

RESULTS

The results of Experiment 1 are given in Table I and show that the nature of the chelating agent present markedly affects the recovery of both soluble iron and of 'total chelate' from the soil.

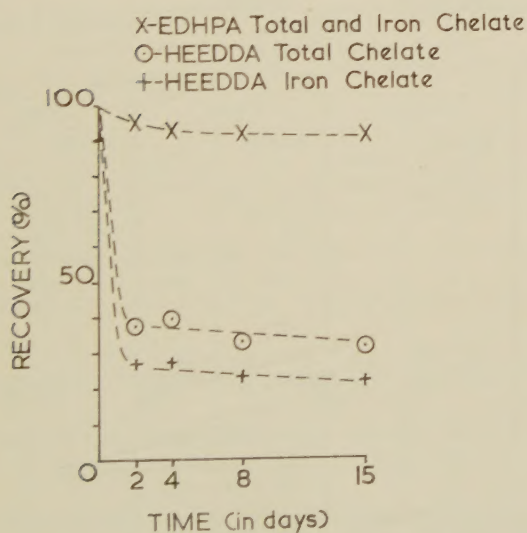
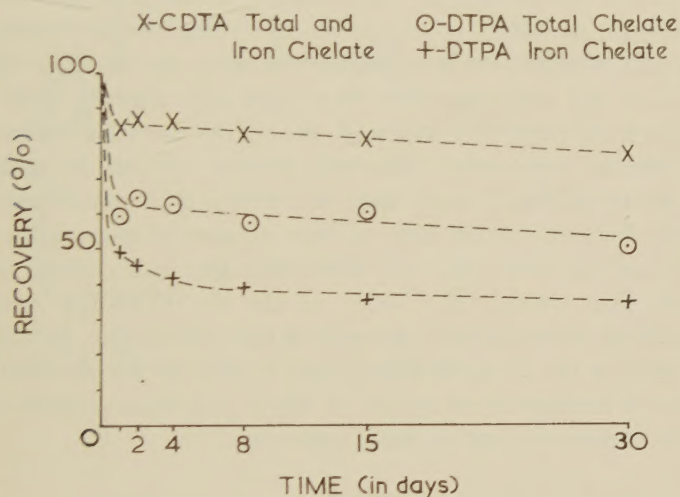


Fig. 1. Effect of time on the recovery of chelates from calcareous soil.
 Approx. 5.0 mg chelated iron added to 50 g soil.

Figure 1 shows the amount and composition of the chelate recovered from the soils treated with 100 ppm chelated iron in Experiment 1. From this it will be seen that with Fe-DTPA only about 50% of the iron remains soluble after 1 day and that this recovery falls with time to about 35% after 30 days. During the same period the amount of 'total chelate' in the extracts is about 60% of the iron chelate applied to the soil. With Fe-CDTA, however, the initial recovery of iron chelate is high, about 85% of that applied to the soil, and this value falls only slightly with time. There is little difference between the values for iron chelate and 'total chelate' recoveries. Also from Figure 1 it will be seen that when Fe-HEEDDA is used there is a very rapid loss of iron from solution, for only about 25% of that applied is recoverable after 2 days contact with the soil; thereafter the iron content of the extracts falls slowly. 30 — 40% of the Fe-HEEDDA added is recovered as 'total chelate' throughout the experiment. In contrast, 90 — 95% of the Fe-EDHPA applied to the soil is recovered after periods of incubation of up to 15 days, and there is little or no calcium chelate present in these extracts.

TABLE II

Chelate content of soil extracts. Experiment 2. Mean of 3 replicates, expressed in μg Fe. ('Total chelate' values in equivalent of Iron)

Iron chelate	Time of contact days	Treatment levels											
		2.5 ppm			5 ppm			25 ppm			50 ppm		
		Soluble iron		Total chelate	Soluble iron		Total chelate	Soluble iron		Total chelate	Soluble iron		Total chelate
		Color.	S/P.		Color.	S/P.		Color.	S/P.		Color.	S/P.	
Fe-DTPA	0				248			1240			2480		
	4				19	36	150	260	308	746	870	945	1000
	15				10	22	168	167	242	735	565	685	750
Fe-CDTA	0	157			315						3150		
	4	130	120	130	253	260	260				2650	2630	2680
	15	120	120	128	247	236	262				2500	2440	2480
Fe-HEEDDA	0				244	253	254				2440	2540	2580
	4				25	66	102				460	555	600
	15				20	24	58				390	450	500
Fe-EDHPA	0	134	134	134	268	269	269						
	4	114	119	119	238	238	238						
	15	110	110	110	221	221	221						

Table II gives the results of Experiment 2. The results from this Table for the 15-day period of contact and those for the same interval in Table I have been combined in Figure 2, in order to

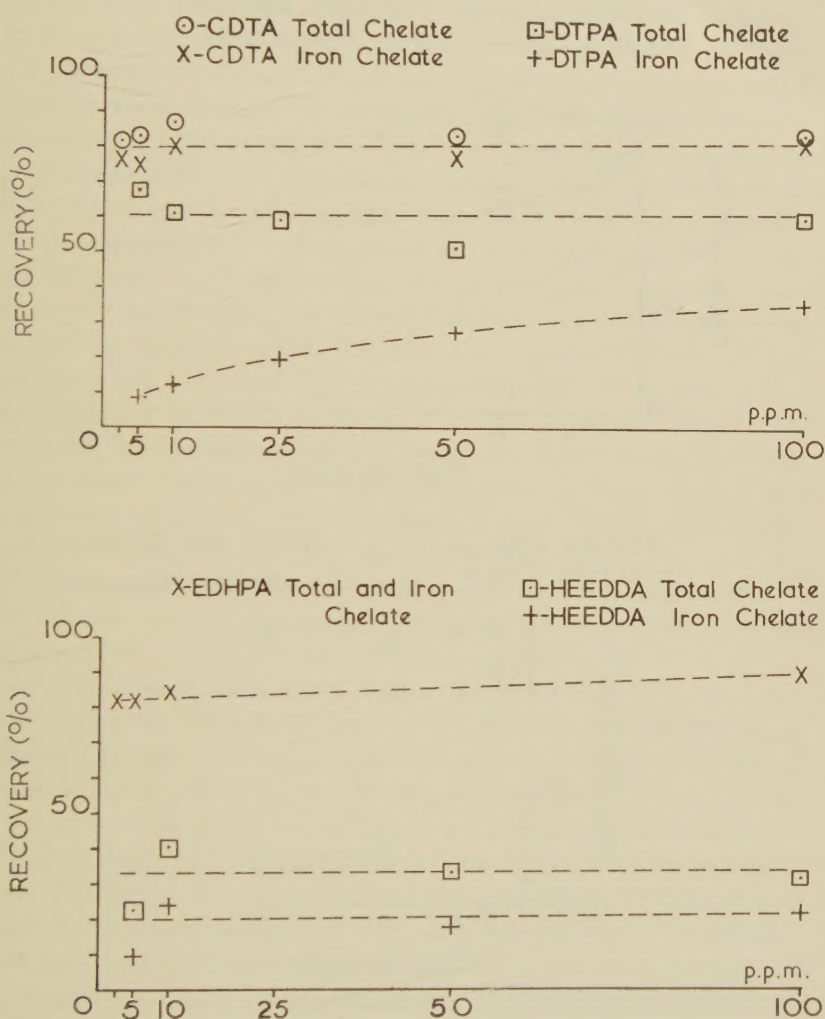


Fig. 2. Effect of rate of application of chelated iron on the percentage recovery of chelate after 15 days contact.

show the effect of the level of chelated iron applied to the soil on the percentage recovery of the different chelates. It will be seen that with Fe-DTPA the proportion of soluble iron in the extracts

increases from under 10% at the 5-ppm level to about 35% at the 100-ppm level. The 'total chelate' recovery varies between 50 and

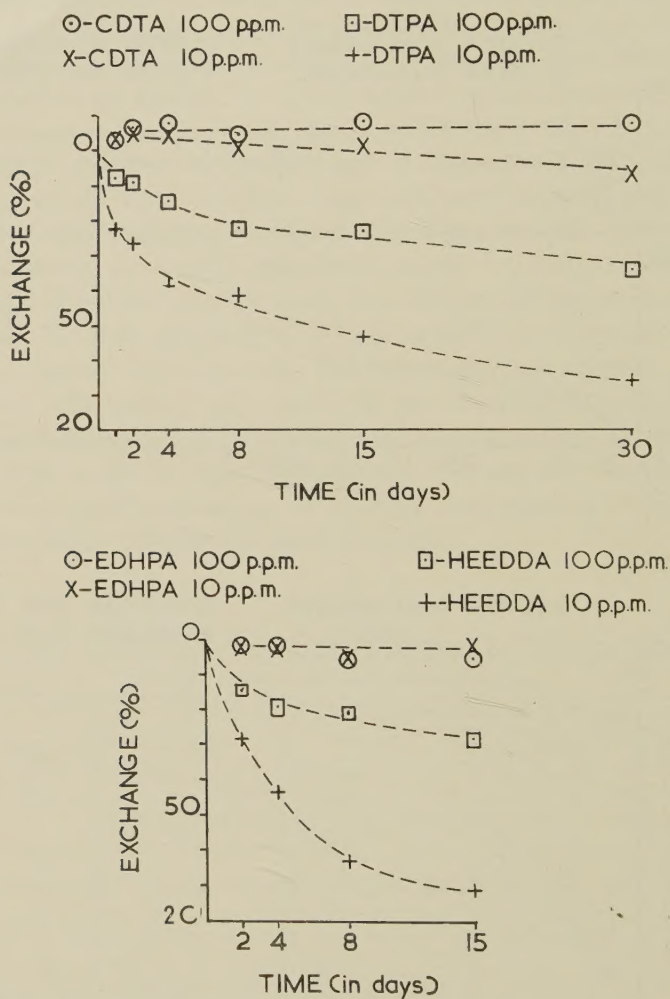


Fig. 3. Effect of chelating agent and rate of application on isotopic exchange of Fe^{59} with soil iron.

$$\text{Isotopic exchange: } \left(1 - \frac{\text{iron by isotope method}}{\text{iron by colorimetric method}} \right) \times 100.$$

60% at all levels of treatment. With Fe-CDTA and Fe-EDHPA, however, the percentage recovery of iron and 'total chelate' is high,

irrespective of the amount applied to the soil. The level of treatment also makes only small differences in the percentage recoveries of both iron and 'total' HEEDDA, but these values are always low. They increase from about 10 to 20% for the soluble iron, and from about 25 to 35% for the 'total chelate', over the range 5 to 100 ppm.

A measure of the amount of isotopic exchange that has taken place between the labelled chelates and soil iron can be obtained by comparing the values for soluble iron given by the isotope and colorimetric methods on the same extract in Table I. If no exchange occurs the two methods should give the same value, but if isotopic exchange does take place the value obtained by the isotope method will be lower. Fig. 3 shows the isotopic exchange that has taken place in Experiment 1, calculated from the isotopically determined iron as a percentage of the iron determined colorimetrically. It will be seen that with both Fe-CDTA and Fe-EDHPA little or no exchange has occurred. With both Fe-DTPA and Fe-HEEDDA, however, considerable isotopic exchange has taken place, especially at the lower treatment level. The exchange rate is rapid at first, then slows with time. After fifteen days the radio-activity corresponds to only about 50% (for Fe-DTPA), and 30% (for Fe-HEEDDA), of the amount of soluble iron determined colorimetrically in the 10-ppm treatments. The corresponding figures for the 100-ppm level are about 75% and 70% respectively.

It will be seen from Table I that for Fe-CDTA, the values for soluble iron by the isotope method are slightly greater than those obtained by the colorimetric method, which results in a calculated value of about minus 5% for the isotopic exchange (Figure 3). This is thought to be due to an error in the colorimetric determination of iron in the original solution, which has resulted in a corresponding error in the factor used to convert the percentage Fe⁵⁹ recovered from the extracts into $\mu\text{g Fe}$. There was insufficient stock solution to repeat the iron determinations, but in an independent experiment performed later with fresh solutions of Fe-CDTA, identical values were obtained by the isotope and colorimetric methods in the analyses of the soil extracts.

DISCUSSION

The overall behaviour in soil of the four iron chelates examined in these experiments is influenced by the same two main factors as

before, namely clay sorption and replacement of chelated iron by calcium⁶. The extent to which these reactions take place, however, varies greatly with the chelating agent present, for Fe-DTPA and Fe-HEEDDA are subject to considerable losses from both causes, while Fe-CDTA and Fe-EDHPA are relatively unaffected.

Our results with Fe-DTPA are in agreement with those from similar laboratory experiments by other workers^{12 17}, and suggest that only by quickly watering this iron chelate into the plant root-zone will it be effective against chlorosis. Differences in manner of application to the soil may account for the varying success that Fe-DTPA has had in the field. Wallace *et al.*^{14 15} reported that Fe-DTPA was more effective than Fe-EDTA in the control of lime-induced chlorosis, but more recently Bould¹ and Gasser and Müller⁴ have found these compounds equally effective, if the solutions are well watered into the soil.

From figure 1 it will be seen that Fe-CDTA is not sorbed or precipitated to any great extent in the calcareous soil used in our experiments. But the behaviour of this iron chelate seems likely to be influenced by the type of clay mineral present, for in similar experiments by Wallace *et al.*¹⁶ with Hacienda loam, (of pH 7.9 and 32% CaCO₃), much higher rates of fixation were reported and the loss increased with time. Moreover, in a Dublin silt loam (of pH 7.8 and 57% CaCO₃), they found that there was complete fixation of Fe-CDTA at 80 ppm Fe after 24 days. The same authors had poor responses to the use of Fe-CDTA in pot tests.

The use of Fe-HEEDDA for the control of lime-induced iron chlorosis on calcareous soils was proposed², on the assumption that it was more stable in alkaline solutions than Fe-EDTA. But this property alone is not sufficient to justify its use in soils, for the high rate of clay sorption and the displacement of chelated iron by the large concentration of available calcium result in a rapid loss of soluble iron (see Figure 1). This result confirms that of Stewart and Leonard¹³, who also found Fe-HEEDDA to be a poor source of iron to chlorotic trees.

Fe-EDHPA is neither adsorbed by clay to any great extent nor is it subject to exchange for calcium in calcareous soil. Similar results from laboratory tests have been reported by other workers^{9 17}. This chelate has given very good results in pot tests with chlorotic plants^{16 18}, and in field experiments⁴.

Steric hindrance by the *cyclo*-hexane ring in the Fe-CDTA molecule may be the cause of the low clay sorption of this chelate found in our experiments. Wallace and Lunt¹⁷ have already attributed the low sorption of Fe-EDHPA to either its strong anionic properties or to space hindrance from the two phenol groups. It would appear from our results, presented here and previously⁶, that the presence of hydroxyethyl groups in the iron-chelate molecule leads to increased adsorption by the clay. The series Fe-EDTA, Fe-HEEDTA and Fe-HEEDDA were adsorbed to about 30%, 50% and 65% respectively under comparable conditions.

One general result of these experiments is that the percentage recovery of 'total chelate' is roughly the same irrespective of the rate of application, implying that the saturation limit of the clay for chelate anions has not been reached. A similar result has been found in our previous work⁶ and elsewhere¹¹, but no explanation can be offered.

The extent to which isotopic exchange takes place in experiments with labelled iron chelates and soil is a factor that should not be ignored. Our results show that the extent varies greatly with the chelating agent present and with the amount of chelated iron used. It seems reasonable to assume that with any particular chelate the rate of isotopic exchange will depend largely on the concentration of soluble iron in the soil; and therefore that the pH of the soil, the organic matter content and the type of clay mineral present will affect the amount of exchange taking place. It is of interest to note that Wallace and Lunt¹⁷ found that Fe-CDTA was subject to considerable isotopic exchange in the calcareous Hacienda loam, but Fe-DTPA was not. In contrast, from Figure 3 it will be seen that the soil, (of about the same pH), used in our experiments the reverse is true. For the above reasons, the results of experiments with labelled iron chelates in soil are suspect if the analyses are made by radioactive assay alone, unless other work carried out under the same conditions shows that the extent of isotopic exchange is negligible. This criticism can be applied in particular to some published results of long-term experiments with plants in soil and of experiments comparing the efficiency of different chelating agents in soil^{12 18}.

Laboratory studies of the type reported here may well serve as a basis for screening tests for new products and the results should

provide information leading to a better understanding of the behaviour of this type of chelate.

SUMMARY

An examination was made of the changes with time in the composition of aqueous extracts of a highly calcareous clay that had been treated with one of the four chelates Fe-DTPA, Fe-CDTA, Fe-HEEDDA and Fe-EDHPA (Fe-Chel 138).

It was found that a rapid fall in the recovery of soluble iron took place with both Fe-DTPA and Fe-HEEDDA due to sorption by the clay and also to replacement of iron in the chelate by calcium from the soil. By using Fe⁵⁹-labelled compounds, it was found that for both these chelates considerable isotopic exchange occurred between the Fe⁵⁹ and the natural soil iron, and that this exchange increased with decreasing rate of application of chelated iron.

Fe-CDTA and Fe EDHPA were found to be comparatively unaffected by contact with the soil; over 80% recovery was obtained after 15 days, with treatments ranging from 2.5 to 100 ppm chelated iron. Negligible isotopic exchange took place with these two chelates.

These results are discussed in relation to previously published results of laboratory experiments with iron chelates and to the treatment of soils for the control of iron chlorosis.

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A LABORATORY STUDY OF NITROGEN MOBILISATION DURING LITTER DECOMPOSITION

by R. T. FENTON *

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Perpetuation of the supply of mineral nutrients to forest crops is ultimately dependent, apart from any extraneous additions by man, on the weathering of mineral material and the release of mineral nutrients from vegetable debris falling on the soil. Usually the slowness of the weathering process means that mineralisation of plant debris provides the greater amount of nutrients for further tree growth in the immediate future.

The content of mineral nutrients in the litter of different plant species can be readily determined by chemical analysis. Such analyses are, however, not a reliable guide to the assessment of plant nutrients which will readily become available for subsequent plant growth, since a more or less large proportion of these nutrients may, in one way or another, have been rendered temporarily unavailable. It is possible that the proportion of unavailable nutrients and the degree of unavailability (*i.e.* the time required before they are released) may vary considerably according to the plant species producing the litter.

It is desirable that a method of following the release of mineral nutrients from litter decomposing under controlled conditions, which approach as closely as possible to natural ecological conditions as far as soil organisms are concerned, should be used.

In the soil-percolation technique, Lees and Quastel¹⁰ have provided a means of studying soil processes quantitatively under controlled conditions more closely approaching the biological optimum than many methods previously available. A modified percolation apparatus devised by Handley⁷ has been used to study the

* Now with the New Zealand Forest Service.

release of nitrogen into a percolation fluid when milled litter is added to soil in a field moist condition, without preliminary drying, so that the original microflora is preserved. The release of nitrogen was studied since the investigations of others indicate that deficiency of this nutrient often occurs in forest soils and hinders tree growth.

Greenwood and Lees⁶ consider that in the case of amino acids decomposing in soil, measurement of carbon-dioxide production is a more satisfactory measure of decomposition than the measurement of mineralized nitrogen because of the reutilization of mineralized nitrogen in the synthesis of microbial protein. The object of the present study, however, was to ascertain the net amount of nitrogen liberated into the percolating fluid, in a form available for absorption by plant roots, when litter originating from different plant species is added to soil through which water and air are subsequently percolated. Any reutilization, for synthesis of microbial protein, of nitrogen released by mineralization of previously unavailable litter nitrogen would mean that this nitrogen was still unavailable for plant growth. A study of the biochemical processes concerned in the liberation of nitrogen during litter decomposition was outside the scope of this work.

MATERIALS AND METHODS

The percolation apparatus

Since the decomposition of forest litter is often a relatively slow process it is most desirable that it should be possible to continue the observations on the soil and litter mixtures for several months at least. As large a mass of soil and litter mixture as was conveniently possible was used so that changes in the nitrogen content of the percolation fluid could be detected more readily.

A diagram of the percolation apparatus is shown in Figure 1. The tube *A* in which the soil and litter mixture is placed is approximately 40 cm in length and 4 cm in diameter. This tube has a glass rim *B* with a central hole 1.3 cm in diameter through which the percolating fluid passes. A porcelain filter disc (diameter 20 mm) is placed over the central hole and a piece of nylon net covers both the disc and the glass rim. This system effectively prevents movement of soil into the lower part of tube *A*. A layer of acid washed

quartz grit is placed on top of the soil column *C* and a porcelain filter disc (diameter 20 cm) on top of the grit; these serve to distribute the percolation fluid over the surface of the soil column and also to prevent compaction of the soil as the percolation fluid drops on to the column of soil. The percolating fluid is directed on to the centre of the surface of the soil column by a short tube *D*. This tube fits, by means of a ground glass joint, into the side arm *E*, so that it can be removed for insertion and removal of the soil sample. When the soil and tube *D* are in position the upper opening of tube *A* is made airtight by means of a rubber stopper. The percolate reservoir *F* of 1.25 litres capacity, and containing initially 1 litre of distilled water, is 44 cm high and 6.5 cm in diameter. The side arm at the lower end of the reservoir is connected to the lower end of the soil tube by elastic, nontoxic, plastic tubing. The glass tube *G*, by means of which percolate is delivered to the top of the soil column has an internal diameter of 3.0 mm. The tube *H*, the diameter of which is of little consequence, delivers compressed air to the bottom of the percolate reservoir. This helps to keep the percolate stirred up. Compressed air is first washed by bubbling through sulphuric acid to remove ammonia and then by bubbling through distilled water to remove any droplets of sulphuric acid and also to saturate the air with water vapour to prevent evaporation of the percolate. It has been found that it is desirable to pass the washed air through a Dreschel gas wash-bottle for each apparatus, when a number are being run in parallel, in order to stabilize the pressure of the air supply to each apparatus. The air supply to each apparatus was regulated by two screw clips, which enabled a sensitive control to be obtained, until the stream of bubbles was as nearly as possible the same in all the sets of apparatus. At the beginning of an experiment the relative levels of tube *A* and the percolate reservoir *F* are so adjusted that the water level reaches half way up the part of the tube *A* which is below the soil sample. The lower end of tube *G* is adjusted so that it just touches the surface of the water in the percolate reservoir *F*. Air bubbling through the percolate results in an increase in pressure above the percolate. This causes some of the percolate to move into the lower part of tube *A*. When contact between the surface of the percolate and the bottom of tube *G* is broken, the small amount of percolate which had moved into tube *G* moves slowly upwards as the air pressure in the percolate reservoir

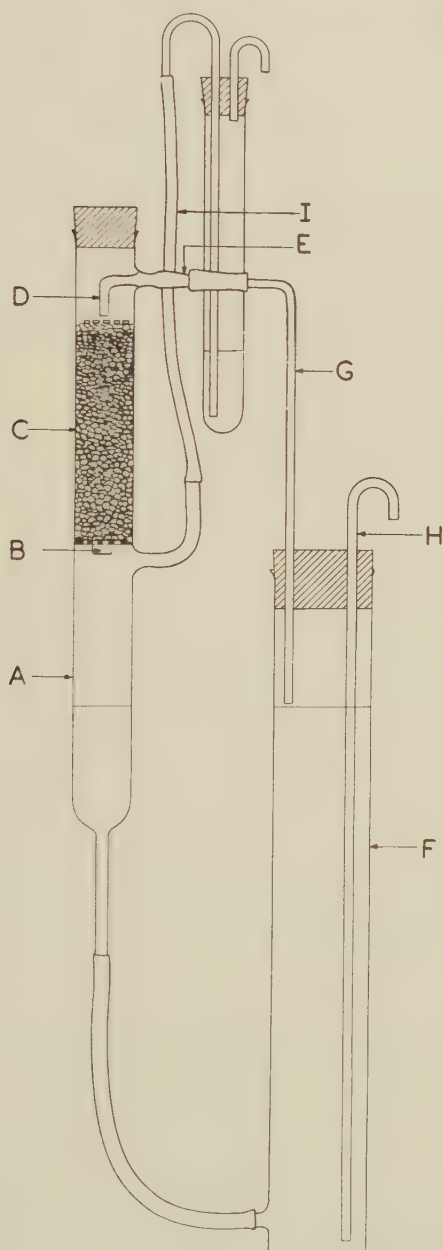


Fig. 1. Percolation apparatus.

F increases. The small amount of fluid is eventually discharged on the filter disc lying on top of the grit covering the soil. Then air from the percolate reservoir passes up tube *G*, through the soil mass and out through tube *I*, where it bubbles through sulphuric acid to trap any gaseous ammonia released from the soil column. At the same time fluid passes back from the lower part of tube *A* to the reservoir *F* via the plastic tube until it reaches the bottom of tube *G* when another small amount passes into this tube, and so the cycle continues. Any nitrogen released into the percolate is determined by analyses of samples removed from the apparatus at approximately 14 day intervals.

Litter material

The samples of litter used in the experiment were collected in December 1954. The leaves were air dried and, after being lightly brushed to remove particles of contaminating material, milled to pass a 2-mm mesh sieve.

The litter of two tree species – *Betula* sp., and *Pinus radiata* – was used in the experiment. The total-nitrogen content of each litter is shown in Table I. Birch has the reputation of being an important soil-ameliorating species (*e.g.* Dimbleby²) in the coniferous forests of northern Europe. The litter of *Pinus radiata* on the other hand has a low nitrogen content. This species is an important exotic conifer in current forestry practice in the Southern Hemisphere and the effects of pure stands are already being investigated in New Zealand¹². The litter of these species was used because of the contrasting nitrogen contents and also because of the possible bearing of the results on silvicultural practice in *Pinus radiata* stands.

TABLE I

Total-nitrogen content of oven dry litter	
<i>Betula</i> sp.	1.58%
<i>Pinus radiata</i> (D. Don). . .	0.62%

Soil

The soil used in the experiment was a brown forest soil which had developed under a stand of mixed broadleaf trees, shrubs and herbs on material derived from Coral Rag Limestone.

As the annual litter fall disappears within one year on this site it

was considered that the soil would be very active biologically and would therefore be suitable for the study of litter decomposition under experimental conditions.

The soil was collected on the day previous to the commencement of the experiment from the uppermost six inches. The sample was cleaned of gross mineral and organic particles before the fraction passing a 3-mm sieve and retained by a 1.5-mm sieve was collected without being dried in any way, for use in the experiment. The aggregates thus obtained disintegrated within one month in the percolation system even when percolated at very slow rates. Soil conditioner in the form of 0.3 g Krilium (Merloam) to 120 g of moist soil was found to maintain the stability of the aggregates when continually percolated for at least 200 days. According to Quastel¹³ the presence of Krilium does not interfere with the process of nitrification nor with the availability of nutrients.

The percolating fluid

Distilled water was used as the percolating fluid. When samples of the percolate were removed for analysis the concentration of solutes was not altered in the remaining percolate by addition of water to replace the volume of the sample removed. Instead, the volume of the sample was replaced by inert solid material (glass stoppers).

Experimental procedure

Five sets of apparatus were used. The amounts of soil and the various materials added to the soil in each case are shown in Table II. It will be observed that equivalent amounts of litter, based on total-nitrogen content, were used in each case, including that in which a mixture of birch and pine litter was used. An experiment in which a mixture of birch and pine litter was used was included on account of the widely held view that the litter of some species assists in, or accelerates, the decomposition of that of other species (Johnston⁸). An amount of casein having a similar content of nitrogen as the litter was added to the soil in one case to ascertain the effect of addition of relatively pure and readily decomposable protein in the absence of added carbohydrate or other non-nitrogenous organic material.

Air at a pressure of 11.5 cm Hg was used throughout the ex-

TABLE II

Apparatus	Column	Litter or casein				Soil			Krillium
		Weight of air dried material used (g)	Moisture content (%)	Oven dry weight (g)	Total nitrogen content (mg)	Weight of moist soil used (g)	Moisture content (%)	Oven dry weight of soil (g)	
1	Soil + casein	0.300	—	—	47.50	120	49.5	60.6	0.3
2	Soil control	—	—	—	—	120	49.5	60.6	0.3
3	Soil + birch litter	3.017	12.93	2.672	42.11	120	49.5	60.6	0.3
4	Soil + birch litter + pine litter	1.510	12.93	1.337	(21.07)	120	49.5	60.6	0.3
		3.753	12.48	3.336	(20.75)				
					41.82				
5	Soil + pine litter	7.536	12.48	6.700	41.67	120	49.5	60.6	0.3
						120	49.5	60.6	0.3

TABLE III

Duration of percolation in days	Amounts of NH_4 , NO_3 and NO_2 nitrogen (in mg) present in the percolate at the various times of sampling in each system									
	Ammonium nitrogen-(mg)					Nitrate nitrogen (mg)				
	Birch	Mixed litters	Pine	Soil control	Casein	Birch	Mixed litters	Pine	Soil control	Casein
21	0.2	1.0	4.4	3.1	2.5	—	—	—	—	15.0
35	—	1.4	2.6	0.4	1.0	—	—	—	—	28.6
48	1.6	1.6	0.8	0.8	1.6	—	—	—	—	31.8
63	—	0.6	0.4	1.2	0.8	—	—	—	—	30.9
77	—	—	—	0.7	2.3	—	—	—	—	32.9
88	—	—	—	1.7	1.5	—	—	—	—	31.3
105	0.4	1.3	0.6	1.1	1.3	—	—	—	—	35.4
115	—	0.6	1.0	0.6	—	—	—	—	—	35.9
133	—	—	—	0.7	—	—	—	—	—	41.7
147	—	—	—	—	—	—	—	—	—	12.0
161	0.9	—	—	0.7	—	—	—	—	—	16.0
175	—	—	—	—	—	—	—	—	—	40.8
189	0.4	—	—	—	—	—	—	—	—	38.0
218	—	2.0	1.5	1.0	0.4	—	1.2	—	—	38.1
240	—	1.0	—	—	0.5	—	—	—	—	39.0
	—	—	—	—	—	12.5	1.4	1.5	19.2	37.5
	—	—	—	—	—	15.6	—	—	21.8	36.2

Gaseous ammonia was not released during the experiment.

periment which continued for more than 200 days. At the end of this time, the structure was still maintained except in the case of those aggregates broken down by the activity of worms.

The experiments were carried out in a dark room to prevent the growth of algae, at a temperature of $20.5^{\circ}\text{C} \pm 2^{\circ}\text{C}$.

Method of sampling

The percolate was sampled by disconnecting the air outlet tube *I*, passing a narrow rubber tube into the fluid in the lower part of tube *A* and removing a 20-ml sample. The ensuing change in level of the percolating fluid was compensated either by adjusting the position of tube *G* or by adding glass stoppers or similar material to the percolating fluid in the reservoir *F*.

Analytical methods

The total-nitrogen content of the litter was determined by the semi-micro Kjeldahl method of Cole and Parks¹.

Ammonia nitrogen in the percolate samples was determined in 10-ml aliquots by the semi-micro method of Cole and Parks¹.

Nitrate nitrogen in the percolate samples was determined in 5-ml aliquots by the phenoldisulphonic-acid method as used by Fred and Waksman³.

Nitrite nitrogen in the percolate samples was determined in 5-ml aliquots by the Griess-Ilosva method (Lees and Quastel¹⁰).

EXPERIMENTAL RESULTS

Table III shows the amounts of ammonium, nitrate and nitrite nitrogen present in the percolating fluids at the time of each sampling.

Table IV shows the total mineral nitrogen, including the cumulative nitrogen removed in successive samples, liberated during the course of the experiment at the various times of samplings.

In Fig. 2 the results in Table IV are shown graphically.

In the case of the experiments in which litter was used, but not in the others, a growth of fungal mycelium was observed, both above and below the upper surface of the soil, on the surface of the soil-containing tube.

Enchytraeid worms developed in all the soil columns except that to which casein had been added. Visual observation indicated that their activity had produced a deterioration of the crumb structure (Plate I).

TABLE IV

Total nitrogen (in mg), including the cumulative nitrogen removed in the successive samples, liberated during the course of the experiment at the various times of sampling					
Duration of percolation in days	Birch	Mixed litters	Pine	Soil control	Casein
21	0.2	1.0	4.4	3.1	18.5
35	—	1.4	2.7	2.9	31.8
48	1.6	1.6	0.9	4.3	34.4
63	—	0.7	0.6	7.0	33.3
77	—	0.1	0.2	7.4	37.5
88	0.4	1.4	0.8	10.2	35.9
105	1.4	0.7	1.2	10.9	40.5
115	1.8	0.1	0.2	11.7	40.5
133	3.8	0.1	0.2	13.2	47.2
147	6.2	0.1	0.2	18.2	47.3
161	7.3	0.1	0.2	14.9	45.5
175	8.8	1.3	0.2	15.7	46.6
189	9.9	2.2	1.7	20.1	49.0
218	13.5	1.2	0.2	22.2	48.0
240	17.0	1.6	1.7	25.5	47.8

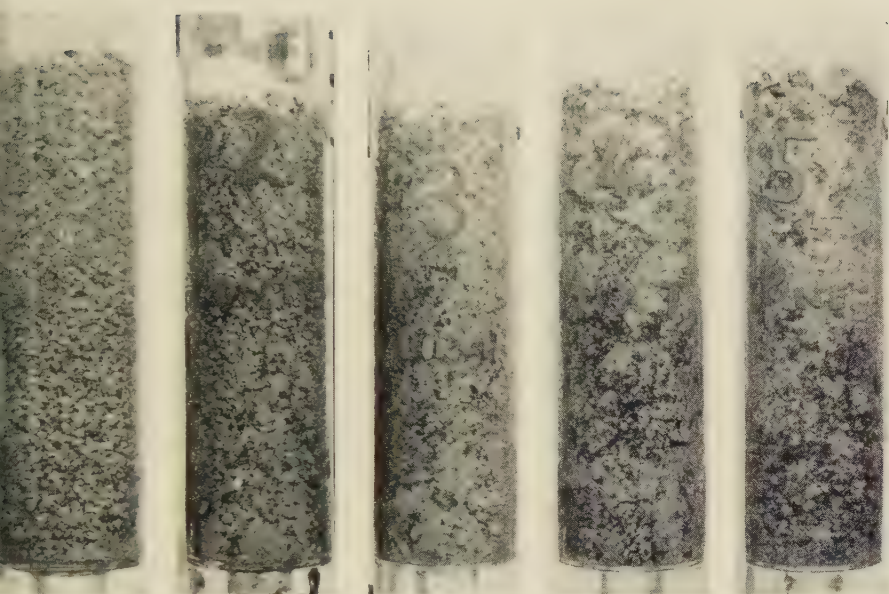
DISCUSSION

The fact that Enchytraeid worms were able to develop and persist over a considerable period of time to the end of the experiment, is an indication that conditions in the soil columns were suitable for considerable biological activity since these animals require the presence of free water and a relatively high oxygen concentration (Kevan ⁹). The development of the worms was not expected and, because of the complexity of the systems involved, it is not possible to estimate their ultimate effects on the soil systems.

That conditions favourable for biological activity were provided is also indicated by the rapid release of mineralized nitrogen into the percolating fluid of the soil column to which casein had been added.

Although a very slow rate of percolation was used, the rapid increase in the amount of mineralized nitrogen in the percolating fluid of the soil column containing casein during the first 35 days is perhaps an indication that mineralization of nitrogen in the soil columns is reflected sufficiently rapidly by changes in the content of mineralized nitrogen in the percolating fluid.

Whilst the results do not indicate any tendency for ammonia to



Soil + casein

Soil alone

Soil + birch litter

Soil + birch and
pine litter

Soil + pine litter

PLATE I. Appearance of the soil columns after percolation for 172 days.

accumulate they do indicate that conditions are favourable for nitrification.

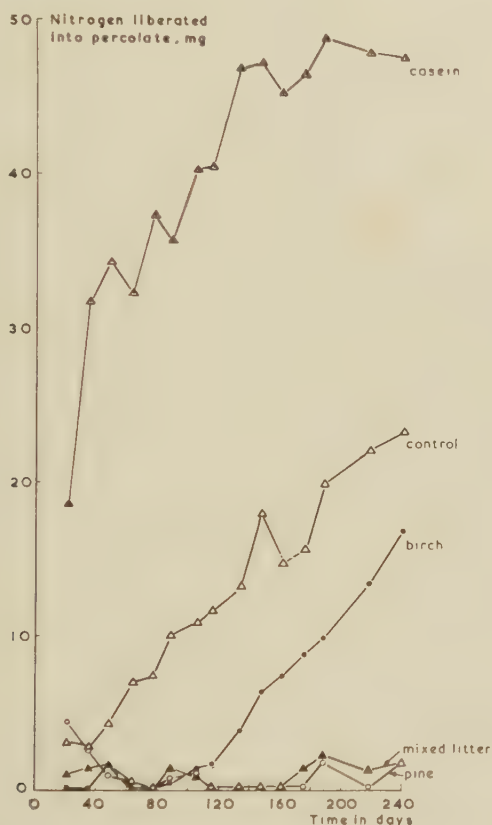


Fig. 2. Total nitrogen (in mg), including the cumulative nitrogen removed in the successive samples, liberated during the course of the experiment at various times of sampling.

The results also indicate that addition of litter to the soil brings about a marked diminution in the release of mineralized nitrogen into the percolation fluid. Some degree of inhibition was perhaps to be expected from previous work on the release of nitrogen from litter and amino acids. (Mikola ¹¹, Greenwood and Lees ⁶).

In incubation experiments Glømmé ⁵ found ammonia production to be independent of increases in non-nitrogenous organic matter but that nitrate production increased as the quantity of non-

nitrogenous organic material decreased. He was working with soils varying in organic-matter content from 1–100 per cent. He observed that addition of leaves greatly reduced the amount of nitrate present initially but that after incubation for 120 days the quantity of nitrate became approximately the same whether few or many leaves had been added to the soil. On the other hand Wallace and Smith¹⁴ found considerable differences, 2 and 34.5 per cent respectively, between the release of nitrogen from avocado and orange litter by incubation and plant growth response experiments. Mikola¹¹ found that, despite considerable loss in weight, the amount of nitrogen released from litter after two years was relatively unimportant. He observed in field experiments, that in the case of the litter of *Pinus sylvestris* 85.9 per cent of the nitrogen remained whilst in the case of birch litter 95.9 per cent remained.

In the present experiments the rate of release of mineralized nitrogen from all the soil columns to which litter had been added was very slow, even after 240 days, compared with the release from the control-soil column.

The inhibitory effect of the addition of litter on release of nitrogen is perhaps associated with the relatively abundant non-nitrogenous organic material of the litter.

It is not possible to make a strict comparison of the influence of pine and birch litter on the release of nitrogen from the soil columns from the results of this experiment alone. Further experiments, for example using equal weights of litter instead of quantities of litter containing equal amounts of total nitrogen are required, but circumstances did not allow such experiments to be carried out. It is possible that the differences observed between the soils containing pine and birch litter may be due as much to the larger quantity of pine litter used, as to any differential rate of breakdown. The same comment applies, although to a lesser extent, to the experiment in which a mixture of pine and birch litter was used. In this case the effect of mixing the pine and birch litter has been to inhibit completely the release of nitrogen from the soil column, whereas when birch litter alone was added to a soil column appreciable amounts, although these were less than in the case of soil without additions, were ultimately released.

It is of interest that in some instances the presence of nitrite was definitely detected. This occurred during the period of relatively

abundant production of nitrate and is possibly an indication of a lag phase in part of the nitrification process (Fry ⁴).

The release of nitrate was not detected in the presence of pine litter even though some ammonia was released initially.

The results obtained in the case of the control-soil column and the soil column containing casein indicate that the process of nitrification followed the normal course in which an initial release of ammonia is followed by a sharp increase in the amount of nitrate in the percolating fluid.

Although the results of the experiment do not offer evidence of a marked difference in the behaviour of the litter of pine compared with the litter of birch regarding release of mineralized nitrogen into the percolating fluid, perhaps because of the slowness of the processes concerned, there are definite indications that nitrogen is released more rapidly when birch litter is added to the soil than when pine litter is added to the soil. This may be due to a higher initial C N ratio in the case of the pine litter. Whether this is the case or not the indications are that the addition of birch litter to the soil is more favourable from the point of view of the supply of mineralized nitrogen than the addition of pine litter, although confirmatory experiments are necessary to establish this point with certainty.

The experiments yielded no evidence of the effect of birch litter on the release of nitrogen from soil containing pine litter although the presence of pine litter appeared to inhibit the release of nitrogen from soil containing birch litter. If such an effect of pine litter were to persist over a long period of time then a decline in soil fertility might ensue.

SUMMARY

A percolation method has been used to follow, over a period of eight months, the course of the release of mineralized nitrogen from columns of soil to which various organic substrates including pine and birch litter had been added.

Favourable conditions for biological activity appeared to be maintained throughout the period of the experiment.

Compared with the release of mineralized nitrogen from a column of soil alone or a column of soil to which casein had been added, the release of mineralized nitrogen from columns of soil to which litter had been added was considerably reduced.

There are indications that the addition of birch litter to soil is more

favourable from the point of view of the supply of mineralized nitrogen than the addition of pine litter.

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EINE STUDIE ÜBER DEN ZUSAMMENHANG ZWISCHEN BODENTYP, KLIMA UND VEGETATION IN ECUADOR

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EINLEITUNG

In Ecuador demonstriert sich in ausserordentlich schöner Weise ein Zusammenhang zwischen Bodenformationen, Vegetation und Klima, welches in diesem Lande auf verhältnismässig kleinem Raum regional enorm grosse Unterschiede aufweist.

Seit der Gründungszeit der Bodenkunde, war das Klima stets als wichtiger, bodenbildender Faktor anerkannt. Besonders in grossräumigen Ländern mit einigermaßen einheitlicher Geologie und Landform, erwiesen sich die Bodenverhältnisse in überwältigender Weise beeinflusst durch die Klimazonen. Es hat sich allerdings gezeigt, dass neben dem Klima auch andere variable Faktoren wie beispielsweise die geologische Unterlage, die Landform, die Vegetation, das örtliche Wasser- und Wärmeregime des Bodens von grossem Einfluss auf die Bodenbildung sind. Entsprechend der heutigen Auffassung in der Bodenkunde, haben alle diese Faktoren sowie auch weitere hier nicht genannte, den Boden so geformt wie er sich uns gegenwärtig präsentiert. Selten wirken aber alle Faktoren gleich stark; meistens tritt einer den andern gegenüber dominierend hervor und vermag den Boden zu prägen. Wo z.B. aus irgend einem Grund der normale Wasserabzug aus dem Boden gehemmt ist, bestimmen diese lokalen hydrologischen Verhältnisse den Boden fast vollständig. Wo andererseits örtlich nahe beieinander

* Der Verfasser hatte Gelegenheit im Rahmen der technischen Hilfe der FAO als Berater der ecuadorianischen Regierung für bodenkundliche Fragen, die Böden von Ecuador während eines Jahres zu studieren.

TABELLE I

Kennzeichnende Merkmale einiger Bodentypen Ecuadors							Horizonte, Farbe und Gefüge	Natürliche Vegetation
Bodentyp Bezeichnung	Allgemeines Feuchtigkeits- regime	Humusbildung	Bildung mineralischer Kolloide	Mittlere Tiefgründigkeit der Boden- bildung	Azidität und Basengehalt	Wahrschein- liche Perkolate		
Sierosen	sehr trocken; nie perkoliert; Nassperiode: 1-3 Monate	sehr gering	Schwellton- bildung	flach; ± 60 cm	alkalisch	—	A: hellgrau, grobklumpig, stark bindig	Kaktusbusch
Regur	trocken; selten perkoliert; Nassperiode: 3-6 Monate	gut; schwarzer, kolloider Mull	sehr starke Schwellton- bildung	mässig flach; ± 80-100 cm	neutral oder alkal. sekundäres CaCO ₃	Erdalkali evtl. Alkali	A: schwarz, grobklumpig, stark bindig A-C: hellgrau	Regengrüne Gehölze
Tropische Braunboden	mässig feucht, period.; perkoliert; Nass-: 6-9 Monate	ziemlich gut; dunkler Mull	Schwelltone vorhanden	mässig tief; ± 150-200 cm	schwach sauer	Erdalkali	A: dunkelbraun; bindiges Aggregatgefüge B: stark braun, klumpig	tropischer innergrüner Laubwald
Braun-Latosol	feucht; regelm. perkoliert; 1-3 Monate trocken	mässig; dunkler Mull	im Obergrund Tonbildung, im Untergrund sesquioxydreich	tief; ± 200-300 cm	ziemlich sauer	Erdalkali und SiO ₂	A: braun; lockeres Aggregatgefüge B ₁ : stark braun, bindig B ₂ : rot und grau	warmer Regenwald
Gebroter- Latosol	dauernd feucht; stark perkoliert	schwach bis fehlend	Kaolin; im Untergrund sesquioxydreich	sehr tief; über 300 cm	sauer	SiO ₂	A: gelb, locker, aggregiert B: rot und grau, bindig	warmer Regenwald
Organo Latosol	dauernd feucht; stark perkoliert	stark; schwarzer Mörtumus; z. T. Rohhumus	Kaolin; im Untergrund sesquioxydreich	tief; ± 300 cm	sauer	SiO ₂	A ₁ : schwarz, sehr porös A ₂ : gelb, porös B: rot grau, bindig	temperiert. Regenwald
Schwarzer Andenboden	mässig feucht; period. perkoliert; ab und zu trocken	stark; schwarzer, kolloider Mull; selten Mör	Allophan; mässige Tonbildung	ziemlich tief: 150-250 cm	schwach sauer bis sauer	Humus, SiO ₂ und Erdalkali	A: schwarz; poröses Schwammgefüge A-C: hell, bindig	Horstgras- prärie
Brunisem der Anden	ziemlich trocken; sehr schwach perkoliert	mässig; kolloider Mull	mässige Tonbildung	mittel; ± 100 cm	neutral	SiO ₂ , Erdalkali evtl., Alkali	A: dunkelbraun, locker, aggregiert A-C: oft hart	Buschgehölz
Brauner Wüstenboden	sehr trocken; nicht perkoliert	fast fehlend	fast fehlend	sehr flach: ca. 30-50 cm	alkalisch	—	A: hellgrau, sandig A-C: locker, sandig	offener Kaktusbusch

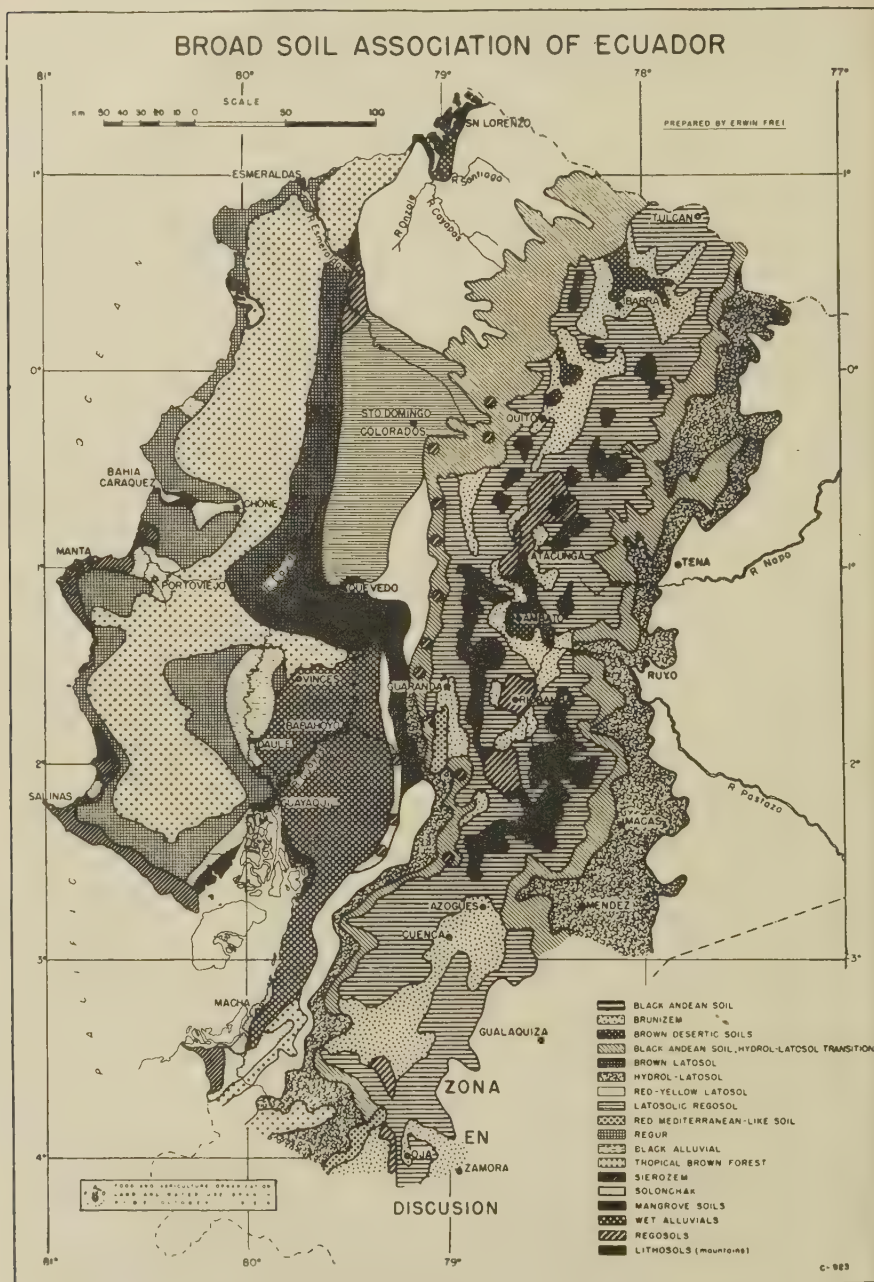
Böden auf reinem Kalk- und granitischem Gestein beobachtet werden können, hat man den Eindruck, die geologischen Verhältnisse seien allein ausschlaggebend für die Bodenausbildung. Ferner haben neuere pflanzensoziologisch-bodenkundliche Untersuchungen auf einen Zusammenhang zwischen Boden und Vegetationsausbildung hingewiesen, sodass bestimmte Bodenausbildungen, bestimmten Vegetationseinheiten zugeordnet werden können oder umgekehrt. Und schliesslich vermag auch das Relief auf die Bodenbildung einzuwirken, denn man wird z.B. am Steilhang eines Tales oder Gebirges andere Böden erwarten als in den Talsohlen.

Ohne die Bedeutung dieser vielfältigen Faktoren für die Bodenbildung zu verkennen, erweist es sich doch als zweckmässig, dass man sich bei bodenkundlichen Uebersichtsstudien auf grossen Flächen in erster Linie an den Faktor Klima hält. Die Gliederung des Territoriums von Ecuador in generelle Bodentypen (siehe Figur 1) ist zugleich auch eine Abgrenzung von Klimaregionen und somit von Gebieten mit unter sich verschiedenen landwirtschaftlichen Entwicklungsmöglichkeiten.

Bevor wir zu Besprechung der Bodentypen im einzelnen übergehen, sei auf die Tabelle I und die Figur 2 verwiesen, wo ein Ueberblick über die wichtigen, kennzeichnenden Merkmale dieser Böden gewonnen werden kann.

Von grösster Bedeutung für die Bodenbildung erweist sich stets die Art der Durchfeuchtung und Perkolation der Bodenprofile. Das Wasser ermöglicht die chemische Verwitterung des Bodenmaterials, wobei seine Wirksamkeit bei erhöhter Temperatur wesentlich intensiver ist, entsprechend seiner grösseren Eigendissoziation. Bei Wasserübersättigung des Bodens erfolgt Perkolation und damit verbunden Filtrationsverlagerungen von Bodenbestandteilen, wodurch viele Bodentypen erst ihre charakteristischen Horizonte erhalten.

Die Art der Humusbildung ist für die Beurteilung von Bodenprofilen ebenfalls von grosser Bedeutung. Sie gibt Anhaltspunkte über die Menge des Anfalls an organischen Rückständen, deren Einmischung in das Bodenprofil und über die biologische Aktivität beim Abbau. Die Humusform lässt mancherlei Rückschlüsse zu über die physikalischen und chemischen Bedingungen während der Humusbildung.



Figur 1. Generelle Bodentypen von Ecuador.

(Bodenkarte herausgegeben von der Food and Agriculture Organisation der UN, Rom)

Die Bildung, Anreicherung oder Auswaschung mineralischer Bodenkolloide vermag gewisse Bodenprofile zu kennzeichnen. Das hervorstechendste Merkmal der Regurböden z.B., ist neben den dunklen Humuskolloiden, die grosse Menge an Schwelltonen im Oberhorizont, wodurch der Boden sein charakteristisch klumpiges und rissiges Gefüge erhält.

Die Tiefgründigkeit der Böden kann lokal wohl sehr variabel sein; die mittlere Tiefgründigkeit, statistisch aufgefasst, ist aber dennoch ein sehr instruktives Profilmerkmal.

Azidität und Basengehalt des Bodens sind an den Bodentyp gebundene Merkmale, sofern eine genügende Variationsbreite akzeptiert wird. Unterschiede in der chemischen Zusammensetzung des Muttermaterials können jedoch besonders bei jungen Bodenprofilen wesentliche Abweichungen von der Norm bedingen.

Die bei der Perkolation der Bodenprofile verlagerten, kennzeichnenden Substanzen sind nicht immer leicht festzustellen. Häufig können sie jedoch chemisch oder optisch direkt nachgewiesen werden. Die Art der verlagerten Kolloide oder Salze geben weitere Aufschlüsse über die Dynamik der Bodenbildung.

Horizontfolge, Farbe und Gefüge sind Eigenschaften des Bodenprofils, die für dessen Klassifikation von Bedeutung sind. Manche kennzeichnende Vorgänge bei der Ausbildung eines Bodentypes, lassen sich äusserlich an einer besonderen Farbtönung oder an einem speziellen Gefüge der Bodensubstanz leicht erkennen.

Die natürliche Vegetation steht häufig in engem Zusammenhang mit dem Bodentyp; wir konnten dies auch im hier zu besprechenden Beispiel deutlich erkennen. Die natürliche Vegetation wird deshalb erwähnt, aber mangels botanischer Studien, sind die hier in dieser Beziehung gemachten Angaben jedoch sehr fragmentarisch.

ERGEBNISSE DER STUDIE

1. *Die Sierosemböden im Küstentrockengebiet unter Kaktus-Busch Vegetation*

Der südliche Teil der ecuadorianischen Küste ist sehr niederschlagsarm; dadurch entsteht eine Halbwüste, die sich südwärts nach Peru fortsetzt und dort grössere Gebiete in Anspruch nimmt. Pro Jahr erhält der verhältnismässig schmale, trockene Küstenstreifen Ecuadors höchstens 250 mm Regen und zwar ausschliesslich

während der tropischen Regenzeit von Januar bis März, die übrigen neun Monate des Jahres sind absolut regenlos. Lokale Meerwinde bewirken zwar während der Trockenzeit oft Bewölkung, zu Niederschlägen kommt es aber nicht, weil der Humboldtstrom die Luftmassen über dem Meer ziemlich abkühlt. Ueber dem Land erwärmt sich die Luft wieder und gibt vorerst kein Wasser ab. In dieser Halbwüste herrscht ein warmes Klima, das jedoch bei 23° bis 24°C Jahresmittel um 1 bis 4°C weniger warm ist als in Landesinnern. Die Temperaturschwankungen sind gering, was für äquatoriale Gebiete ziemlich allgemein typisch ist. Während der langen Trockenzeit wird die Halbwüste völlig dürr. Nur die zahlreichen Kaktusgewächse vermögen das eintönige Grau zu unterbrechen. Auch die Bodenoberfläche ist kahl, völlig ausgetrocknet, häufig stark rissig und hart, sowie meistens durch eine sandige Verwehungsschicht bedeckt. Doch während der Regenzeit begrünt sich diese Wüste rasch. Dadurch wird eine gewisse kleine Menge organischen Materials produziert, das die Grundlage für eine sehr beschränkte Humusbildung gibt. Die kurze, jährliche Nässeperiode ermöglicht die Bildung von Tonmineralen in der 30-40 cm mächtigen Oberflächenschicht. Hier sind oft Tongehalte bis zu 40% zu finden. Sierosemprofile werden nie perkoliert, weshalb sich die gelösten Salze im Boden wieder während des Austrocknens abscheiden. In der Regel findet man deshalb neutrale oder alkalische Reaktionen und nicht selten kommen Gipskristalle vor.

Diese grauen, tonigen Halbwüstenböden sind in Ecuador nicht landwirtschaftlich genutzt. Eine Nutzung käme auch nur unter intensiver Bewässerung in Frage und das Herleiten grosser Wassermengen dürfte hier ein Problem sein. Wo aber genügend Bewässerungswasser zugeführt werden könnte, wäre eine Inkulturnahme des sanft welligen Landes möglich. Gewisse Nachteile bilden die harte, klumpige Struktur des Oberbodens, die geringe Wasserdurchlässigkeit und ab und zu etwas hoher Salzgehalt.

2. Die Regurböden im Gebiet der regengrünen Gehölze

Landeinwärts, an den Halbwüstengürtel anschliessend, folgt ein niedrig gelegenes, jedoch häufig steil kupiertes Hügelland. Geologisch handelt es sich um tektonisch gehobene, häufig verworfene und etwas schräg gestellte Sedimentschichten des Tertiärs oder stellenweise sogar des jungen Quartärs. Tschopp⁸ nimmt an, dass die

Gebirgsbildung in den Anden auch im frühen Quartär noch angehalten hat und in dieser Zeit mit einer tektonischen Hebung bis gegen 1000 m zu rechnen ist. Bei dieser Hebung war natürlich auch das Andenvorland in Mitleidenschaft gezogen, das Küstengebiet Ecuadors ist gegenwärtig noch ziemlich erdbebengefährdet.

Das Gebiet der Regurböden erhält jährlich etwa 500 mm Niederschläge, die in der Regenzeit während 3–4 Monaten fallen. In dieser Zeit entwickelt sich eine recht üppige Vegetation. Der Strauchwald mit zahlreichen, mächtigen Ueberständerbäumen erreicht undurchdringliche Dichte. Zu Beginn der Trockenzeit erfolgt ein allgemeiner Blattfall und die Erdoberfläche bedeckt sich mit einer mehreren Zentimetern dicken, dünnen Laubschicht. Nur die wenigen hartlaubigen Sträucher und Kaktusarten bleiben grün. Mit dem völligen Austrocknen der Erdoberfläche entstehen weite, tiefe Risse, in die ein Teil des Pflanzenabfalls hinab gleitet. Alles Leben bleibt erstarben, bis mit Pünktlichkeit des Sonnenumlaufes die Regenzeit sich wiederholt. Dann schliessen sich die Bodenrisse und das organische Material erfährt einen raschen Abbau, der zur Bildung dunkel gefärbter bis schwärzlicher Humuskolloide führt. Dieser schwarze, tonige Oberboden verleiht dem Profil sein typisches Gepräge. Tropische, schwarze Böden sind bereits aus Indien, Australien und Afrika bekannt (Mohr und Van Baren⁶). Eines ihrer wichtigen Merkmale ist das starke Schwinden des tonreichen Obergrundes bei Trockenheit und das Aufschwellen bei Wiederbefeuchtung. Stellenweise ist dieser Vorgang so intensiv, dass die Bodenoberfläche ein kleinhügeliges Mikrorelief („Gilgai“ nach Hallsworth *et al.*) erhält. Der dunkle Obergrundhorizont enthält meist über 50% Ton und ist von grobklumpigem, ziemlich dichtem Gefüge. Er ist neutral und meistens ohne Kalziumkarbonat, dagegen folgt im poröseren, hellgrauen Unterboden eine Zone mit viel sekundären Kalziumkarbonatausblühungen.

Die landwirtschaftliche Produktivität dieser Böden ist beschränkt da sie wegen der hügeligen Landform nur schwierig bewässerbar sind. Auch Baumwolle gibt nur mit Bewässerung einen Ertrag. Glücklicherweise besitzt diese Zone alte, breite Talsohlen mit Alluvialböden, die bei Bewässerung leicht landwirtschaftlich entwickelbar sind.

3. *Die tropischen Braunböden des immergrünen Waldes*

Schreitet man vom Gürtel der Regurböden ostwärts, so kommt man in wenig höher gelegenes Hügelland. Es fällt hier etwas zusätzlicher Regen, der durch die lokalen Meereswinde herangebracht wird. Die jährlichen Niederschläge betragen 1000-1500 mm und sind in der einen Jahreshälfte konzentriert, während die andere ziemlich trocken ist. Immerhin genügt die Feuchtigkeitsversorgung, um einen dauernd grünen Wald gedeihen zu lassen. Dazu trägt bestimmt auch das bedeutend tiefgründigere Bodenprofil bei, das verhältnismässig viel Wasser speichern kann. Der deutlich humose Oberhorizont des Bodens (2-3% Humus), hat gewisse Ähnlichkeit mit dem entsprechenden Horizont beim Regur; doch ist er lockerer, weniger klumpig und weist ein grobes Makroaggregatgefüge auf. Typisch für die tropischen Braunböden ist besonders der, unter dem humosen Horizont folgende, stark braune, sehr tonreiche Mittelhorizont mit 50-60% Ton. Dieser klumpige Horizont geht in 100-150 cm Tiefe allmählich in das stark verwitterte Muttergestein über. Die Bodenprofile sind in der Regel schwach bis mässig sauer (pH 5-6) was auf eine periodische Perkolation während der Regenzeit hindeutet. Immerhin findet keine Tonzerstörung statt, im Gegenteil, es werden offenbar kieselensäurereiche Tone gebildet. Das Eisenoxydhydrat ist in diffuser Verteilung den Tonen angelagert, wodurch das Bodenprofil seine homogen braune Färbung erhält. Landwirtschaftlich handelt es sich um wertvolle Böden, die auch ohne Bewässerung einen Ertrag abwerfen. Anspruchsvolle Kulturen sollten jedoch noch zusätzliches Bewässerungswasser erhalten können, doch ist dies der ungünstigen Landform wegen nur beschränkt möglich. Ausserdem ist der Boden durch das steile Relief sehr dem Erosionsabtrag unterworfen.

4. *Die Braun-Latosole des Regenwaldes mit Trockenzeit*

Dringt man vom Gürtel der tropischen Braunböden noch weiter ostwärts ins Landesinnere vor, so gelangt man in regenreichere Zonen mit mindestens 2000 mm Niederschlag und einer mittleren Jahrestemperatur von 25-26°C. Das Gebiet ist stark hügelig und teilweise von ganz niederen Gebirgsketten durchzogen. Weitaus der grösste Teil dieses Landes ist heute noch vom ursprünglichen, dichten Regenwald bestockt. Die klimatischen Bedingungen gestatten hier bereits die Bildung von Latosolen (oder Laterisolen). Latosole sind

nach Kellogg⁴ rote und gelbe, feinkörnige, leichtverhärtende Böden, die zumindest die Tendenz zur Kieselsäureauswaschung und zur Rückstandsanreicherung der Sesquioxide aufweisen. Die Latosolbildung ist noch zu wenig untersucht, um eine sichere Vorstellung vom Entstehungsvorgang dieser wichtigen tropischen Böden zu haben. Sicher ist jedenfalls, dass eine grosse Zahl verschiedener Latosoltypen vorkommt. Die hier zu beschreibenden Braun-Latosole sind offenbar an mässig nasses, tropisches Klima mit deutlicher Trockenzeit gebunden. Die kurze Trockenzeit von 3 Monaten genügt um die oberen Bodenhorizonte auszutrocknen und die Humus- und Tonbildung hier wesentlich zu beeinflussen. Der zeitweilige Wassermangel hemmt offenbar den völligen Abbau der organischen Substanz, wodurch die Bildung eines verhältnismässig kräftigen humosen Oberhorizontes ermöglicht ist. Etwas tiefer im Bodenprofil folgt ein stark brauner, sehr zäher, tonreicher Horizont der deutlich an die tropischen Braunböden erinnert. Es ist zu vermuten, dass die periodische Austrocknung dieses Horizontes der Bildung und Erhaltung der Tonminerale günstig ist. Ausschlaggebend für die Klassifizierung des Bodenprofils ist der unter dem braunen Horizont anschliessende rot gescheckte Horizont mit grauen und gelben Flecken und Punkten. Dieser latosolische Horizont ist sehr tiefgründig und erreicht erst in 2–3 Metern unter der Oberfläche den Fels. Der Uebergang zum Muttergestein ist nach allen unseren Beobachtungen sehr diffus. Man kann aus diesem allmählichen Eindringen des latosolischen Horizontes in den Gesteinsuntergrund schliessen, dass bei konstant feucht-warmen Bedingungen die Lateritbildung die primäre Verwitterungs- und Bodenbildungsart ist. Sobald Wasser in das Gestein eindringen kann, ist dessen physikalische Zerkleinerung nicht unbedingt notwendig für das Durchgreifen der chemischen Verwitterung und für die Umwandlung in freie Kieselsäure, Sesquioxide und allenfalls Kaolin. Die ursprüngliche Gesteinsstruktur ist öfters auch bei völlig verwittertem Material noch deutlich erkennbar, was für die starke hydrolytische Wirkung des Wassers spricht.

Die Latosole sind ganz allgemein stark erosionsgefährdet, sobald sie von ihrer natürlichen Vegetation entblösst sind. Dies ist leicht verständlich, wenn man an die ausserordentliche Intensität der tropischen Regengüsse und an die Feinkörnigkeit und geringe Gefügestabilität des Bodens denkt. Sehr leicht wird dann der ganze

Oberboden weggeschwemmt und zurück bleibt nur das mehr oder weniger gründlich lateritisch verwiterte Muttergestein. Ob man in solchen extremen Fällen von Lateritvorkommen in amputierten Bodenprofilen noch von Boden im eigentlichen Sinne des Wortes reden kann, ist tatsächlich fraglich. In Ecuador sind glücklicherweise die Fälle solch weitgehender Erosion nicht häufig.

Der nicht erodierte Braun-Latosol ist landwirtschaftlich ein sehr guter, produktiver Boden z.B. für Bananen und Cacao. Tiefgründigkeit und häufige Niederschläge bewirken eine gute Wasserversorgung der Pflanzen. Günstig wirkt sich auch der Humusgehalt des Oberbodens aus und die mässig saure Reaktion ist noch kein Hemmnis für die Entwicklung der Vegetation.

5. *Die Gelbrotten-Latosole des immer feuchten Regenwaldes*

In der Nähe des Andenfusses stauen sich die feuchten Luftmassen und werden zum Aufsteigen gezwungen. Daher kann es hier praktisch täglich regnen und die Summe der Jahresniederschläge beträgt 3000–4000 mm. Während der eigentlichen Regenzeiten sind die Regenfälle viel ausgiebiger und heftiger als in der übrigen Zeit, in der es vorkommen kann, dass mehrere Tage kein Regen fällt. Doch zum eigentlichen Abtrocknen der obersten Bodenschicht reicht es selten. Ganz ähnliche klimatische und bodenkundliche Verhältnisse wie am Westfuss der Anden herrschen auch im östlichen andennahen Tiefland.

Die dauernd feuchtwarmen Verhältnisse (Mitteltemperaturen von 26–28°C), ermöglichen nicht nur eine üppige Pflanzenproduktion jahraus, jahrein ohne Unterbruch, auch der Abbau der Pflanzenrückstände erfolgt sehr intensiv und gründlich. Es kann sich deshalb kein eigentlicher Humushorizont bilden. Hingegen ist im ungestörten Zustand der Boden stets durch eine mehrere Zentimeter dicke, lockere Pflanzendetritus-Schicht bedeckt; darunter folgt unmittelbar der humusarme Mineralboden. Leider muss diese natürliche, organische Bodendecke bei der Inkulturnahme der Böden zerstört werden und die feinkörnige Mineralerde kommt an die Oberfläche. Der 30–50 cm mächtige Obergrundhorizont besteht aus einem ziemlich lockeren, hellgelben oder gelbbraunen Lehm mit verhältnismässig grossen, aber offenbar sehr unbeständigen Aggregaten. Von Eisenhydroxyd-Anreicherungen ist hier makroskopisch nichts zu sehen. In den tieferen Schichten wird der Boden

jedoch zunehmend rot. Man findet dort einen hellroten bis intensiv roten, plastischen Lehm, der immer noch schwach aggregiert ist. Erst in 100–200 cm Profiltiefe folgt ein verhältnismässig kompakter Horizont, der neben seiner intensiv roten Farbe durch die zahlreichen gelben und grauen Punkte und Flecken auffällt. Mit zunehmender Profiltiefe erhalten die hellen Flecken die Oberhand und die hier blassroten Stellen und Aderungen treten mehr und mehr zurück, bis allmählich das Material den ursprünglichen Gesteinscharakter annimmt.

Sofern diese Böden vor Abschwemmung bewahrt bleiben, eignen sie sich gut für die tropische Landwirtschaft. Kommt jedoch der rote, dicht gelagerte, beim Austrocknen leicht verhärtende Untergrund obenauf, so werden Anbauschwierigkeiten nicht ausbleiben. Regeneration des eisenoxydreichen Untergrund-Materials in gutartige Kulturerde ist kaum möglich. Umsomehr lohnt sich ein fachgemässes und vorsichtiges Vorgehen bei der landwirtschaftlichen Entwicklung ursprünglicher Regenwaldgebiete. Die ziemlich tiefe Durchwurzelung der Regenwaldböden und der rasche Mineralstoffumsatz täuschen grosse Fruchtbarkeit vor, die bei landwirtschaftlicher Nutzung dann oft sehr rapid abfällt. Durch regelmässige Ergänzung der mineralischen Nährstoffe soll der Säure- und der Basengehalt dieser Böden reguliert werden.

6. *Latosolische Uebergänge zum Schwarzen-Andenboden im Gebiet des tropisch temperierten Regenwaldes.*

Am westlichen wie am östlichen unteren Hang des Andengebirges erreichen die Niederschläge ihr Maximum. Bei etwa 1000 m Meereshöhe fallen jährlich mehr als 4000 mm Regen. Mit zunehmender Meereshöhe geht die Niederschlagsmenge allmählich wieder zurück bis auf etwa 2000 mm pro Jahr. Es herrscht hier somit ausgesprochen humides Klima, besonders auch wegen der hohen Luftfeuchtigkeit durch die fast ständige Wolken- und Nebelbildung. Mit zunehmender Meereshöhe reduziert sich die jährliche Mitteltemperatur um ungefähr 0,5°C pro 100 m Höhendifferenz. Bei 1000 m Meereshöhe, der unteren Grenze des hier zu betrachtenden Gürtels, beträgt die Mitteltemperatur etwa 20°C. In 3000 m Meereshöhe, der oberen Grenze dieses Gürtels, können wir somit noch ungefähr 10°C annehmen. Dieses humide, temperierte Klima vermag ganz charakteristisch auf die Bodenformation einzuwirken.

Wald- oder Buschvegetation produzieren laufend eine grosse Menge Pflanzenreste, die hier nicht völlig mineralisiert werden können. Als Konsequenz bilden sich mehr oder weniger mächtige Humushorizonte. Dabei ist die Humusform wesentlich verschieden vom Humus der Braun-Latosole im wechselfeuchten Tropengebiet. Hier im immerfeuchten, temperierten Gebiet zwischen 1000 und 2000 m Meereshöhe entsteht ein sehr poröser, schwammiger Humushorizont, der beim künstlichen Trocknen stark an äusserem Volumen verliert. Er ist von schwarzer Farbe, hat jedoch deutlichen Mörhumus-Charakter. Unter diesem bis etwa 40 cm mächtigen, schwarzen Oberflächenhorizont folgt ein gelber Lehm und tiefer der rote, latosolische Lehm. Aehnliche Böden wie diese feuchten Organo-Latosole, wie wir diesen Typ vorläufig benennen, sind von Cline² in Hawaii als Hydrol Humic Latosols beschrieben worden.

Ueberschreiten wir die 2000 m Meereshöhe, so konstatieren wir eine immer stärkere Reduktion des latosolischen Untergrundes. Besonders der sesquioxidgeiche, rote Lehm ist bald nur noch in einer Schicht von wenigen Zentimetern Mächtigkeit vorhanden oder fehlt völlig. Der lockere, gelbrötliche Mittelhorizont, direkt unter dem zunehmend mächtiger werdenden Humushorizont, bleibt jedoch bis auf 3000 m Meereshöhe deutlich erhalten. Nicht selten findet man in dieser Höhe bis 100 cm mächtige, schwarze Oberflächenhorizonte, die nun dem Boden das Hauptgepräge verleihen.

Da die Andenhänge im allgemeinen sehr steil sind, findet man ziemlich selten gut ausgebildete, vollständige Bodenprofile. Häufig ist der Boden kolluvial gestört oder gar völlig aus jungem Blockmaterial bestehend. Die Andenhänge können deshalb nur an Stellen günstiger Landform landwirtschaftlich genutzt werden, im übrigen bleiben sie mit Vorteil der natürlichen Waldvegetation erhalten.

7. Die Schwarzen-Andenböden der Horstgrasprairie

Wenn man an den äusseren Andenhängen aufwärts schreitet und die 3000 m Höhengrenze erreicht, hat sich der Wald sehr stark aufgelockert oder hat bereits schon einer Buschvegetation Platz gemacht. Nun erfolgt der Uebergang in eine vorerst mehr oder weniger strauchreiche Grasprairie. Bei ungefähr 4000 m Meereshöhe wird der Rasen kürzer und noch etwas weiter oben lässt der gute

Bodenschluss zu wünschen übrig. Bei etwa 4200 m Meereshöhe findet man nur noch inselweise Vegetation und bald tritt man in die Regosole oder Lithosole aufweisende Hochgebirgswüste. Ungefähr bei 4800–5000 m ist die Dauerfrostgrenze. Alle Gipfel zwischen 5- und 6 tausend Metern tragen permanent eine Schneekuppe.

Die Berge und Hänge der Anden Ecuadors zwischen 3000 und 4000 m Meereshöhe, von denen wir hier besonders reden, gehören unbestritten den Schwarzen-Andenböden an. Die Temperatur dieses Gebietes ist kühl; sie beträgt im Jahresmittel zwischen 5 und 10°C. Dabei gibt es fast keine Schwankungen zwischen den Monatsmitteln, dagegen besteht eine starke, tägliche Temperaturfluktuation. In der Nacht kann die Temperatur nahe an den Gefrierpunkt sinken, am Tag wird es warm, da in diesen Höhenlagen nur geringe Bewölkungstendenz besteht. Die grosse Sonneneinstrahlung und die mässigen Niederschläge von 1000–2000 mm pro Jahr ergeben ein eher trockenes Klima; doch können übers ganze Jahr Niederschläge fallen. In der tropischen Regenzeit sind sie oft sehr ausgiebig, sodass die Bodenprofile periodisch ziemlich stark perkoliert werden.

Bei Betrachtung eines Schwarzen-Andenbodens fällt vor allem der häufig 100 cm und mehr mächtige, schwarze Oberboden auf, der ziemlich abrupt einem hellen Mineralerde-Untergrund aufliegt. Das Muttergestein besteht vorwiegend aus lockerer oder mässig kompakter Vulkanasche, deren Farbe und chemische Zusammensetzung variieren kann; doch kommen auch andere Muttergesteine vor. Meistens trifft man sandige bis lehmige Körnung; aber auch tonige Varianten sind nicht selten. Ganz allgemein findet man besonders im dunklen Oberboden ein sehr poröses, gut durchlüftetes Bodengefüge von schwacher bis mässiger Bindigkeit. In sandigen Böden sind die Makroaggregate eher unbeständig, tonreichere Aggregate erscheinen jedoch einigermaßen hart. Miller⁵ hat in solchen Böden Anzeichen für das Vorwiegen von nichtkristallinen Tonen (Aluminiumsilikaten) gefunden. Solche Allophane dominieren nach Thorp⁷ sowie Aomine und Yoshinaga¹ und anderen, in den Andoböden Japans, die mit den hier besprochenen Böden gewisse Ähnlichkeit haben könnten. Bei näherer Untersuchung des zwischen 5–15% Humus enthaltenden schwarzen Oberbodens bemerkt man eine deutliche Horizontierung. Der oberflächliche Teil ist stark

dunkelgraubraun gefärbt, während nach unten die Schwarzzintensität zunimmt. Häufig ist der Horizont zwischen 50 und 100 cm Profiltiefe beinahe glänzend bläulich-schwarz. Es handelt sich hier offenbar um einen Humusanreicherungshorizont. Die Wanderung der Humuskolloide ist besonders in tonreicheren Varianten mit ziemlich dichten Aggregaten sehr schön zu sehen, indem sich hier die Kolloide vorwiegend an den Aggregatoberflächen und in den Bodenklüften absetzen, was im Profilschnitt zu einem gefleckten Aussehen des Horizontes führt. Aber auch in allen übrigen Varianten erscheinen die Aggregatoberflächen durch die Humuskolloidkrusten viel schwärzer als das zwischen den Fingern zerriebene Material. Die Art der Bildung und die Ursache der Wanderung dieser schwarzen Humuskolloide ist vorläufig ungeklärt. Wahrscheinlich wird die Grasvegetation und der verhältnismässig hohe Basengehalt des vulkanischen Muttermaterials eine Rolle spielen. Vielleicht sind aber die bodenklimatischen Verhältnisse ausschlaggebend durch den ständigen raschen Wechsel von Abbau fördernden und hemmenden Einflüssen. Der verhältnismässig hohe Gehalt an Natrium und freier Kieselsäure im Muttermaterial, dürfte trotz der sauren Reaktion (pH 5) die Wanderung der Humuskolloide befördern.

Landwirtschaftlich sind diese tiefgründigen Böden, soweit Landform und Klima einen Anbau erlauben, als gut und fruchtbar zu bezeichnen. Es sind die idealen Kartoffelböden. Für Schafe und Rinder bietet die natürliche Grasprairie allerdings eine sehr schlechte Futterqualität, sie könnte aber durch Düngung und zweckmässige Bewirtschaftung verbessert werden.

8. *Die Brunisemböden des Andentales.*

Die Andenkette ist in Ecuador längsgeteilt durch ein mehrere Kilometer breites, hügeliges Hochtal, das durch zahlreiche Querriegel in viele, separat drainierte Bassins zerfällt. Die Entstehung dieses eigentümlichen Hochlandes wird von den Geologen als tektonischer Grabenbruch angesehen, was auch das Vorhandensein der zahlreichen, längst erloschenen und teilweise noch aktiven Vulkane in Nähe der Bruchstellen erklären würde. Dieses Tal liegt auf durchschnittlich 2500 m Meereshöhe und ist somit ziemlich im Regenschatten der Gebirgsketten. Die tropische Regenzeit wirkt sich hier ebenfalls weniger stark aus und die jährliche Regenmenge beträgt nur zwischen 500–1200 mm. Die Niederschläge sind einiger-

massen über das ganze Jahr verteilt, doch sind längere regenfreie Perioden während den tropischen Trockenzeiten nicht selten. Im Verhältnis zur Meereshöhe ist das Klima durch die Muldenlage und die lange Sonnenscheindauer sehr mild, die Mitteltemperatur erreicht mindestens 15°C.

Im Andental sind die Böden nicht mehr schwarz wie im Gebirge. Das wärmere trockenere Klima ermöglicht offenbar nur eine geringere Humusproduktion, jedoch einen intensiveren Abbau der organischen Substanz. Die Farbtönung des Oberbodens ist deshalb dunkelgraubraun oder hellbraungrau. Auf Grund der Ähnlichkeit dieser Böden mit gewissen nordamerikanischen Prärieböden haben wir sie in die Brunisemgruppe gestellt.

Die Bodenprofile zeigen, wie die schwarzen Andenböden, einen sehr einfachen Aufbau. Ein humoser, meist 50–80 cm mächtiger Oberboden liegt mit diffusem Uebergang auf dem lockeren, oft aber sekundär verhärteten Muttermaterial. Der humose Oberboden zeigt in der Regel sandig-lehmige Körnung und ein poröses Aggregatgefüge mit ziemlich schwach beständigen Makroaggregaten. Im Falle des dunklen Brunisems ist dieser Horizont noch ziemlich humusreich und schwach sauer; es sind dies die Bruniseme, die etwa bei 1000 mm Niederschlägen gebildet werden und meist den Uebergang zu den Schwarzen-Andenböden darstellen. Die hellen Brunisemböden mit hellbraungrauem, neutralem Humushorizont, bilden sich im trockeneren Teilgebiet mit 600–800 mm Jahresniederschlägen. Eine Verlagerung der organischen Kolloide ist nicht oder nur schwach festzustellen, dagegen wandert bei der Verwitterung freigelegte Kieselsäure und bildet im Untergrund oft metermächtige, verhärtete Schichten. Sekundär verhärtete Vulkanascheschichten bilden geradezu ein typisches Landschaftsmerkmal des Zwischen-Andentales, denn sie sind häufig durch die Wasserläufe schluchtartig eingeschnitten oder durch Erosion blossgelegt und fallen dem Wanderer sofort auf. Zuweilen weisen die Bruniseme der Anden im unteren Profilteil Kalkkarbonat-Ausblühungen auf, was auf nur teilweise Perkolation der Profile hinweist. Da das Muttermaterial natürlicherweise häufig kalkarm ist, sind diese Ausblühungen aber nicht immer vorhanden.

Die Bruniseme der Anden sind die fruchtbaren Weizen- und Maisböden des Landes. Sie sind seit altersher landwirtschaftlich genutzt und die natürliche Vegetation ist deshalb nicht mehr

erhalten. Immerhin ist anzunehmen dass es sich um Buschvegetation handelt mit Trockenheits-resistenten Arten.

9. *Die braunen Wüstenböden des Zwischen-Andentales*

Zahlreiche Hangflächen und Mulden des Zwischen-Andentales erhalten vielleicht höchstens 200 mm Niederschläge pro Jahr. Ueberall dort verrät eine spärliche, offene Strauch- und Kaktus-vegetation die grosse Trockenheit. Starke Winde verblasen die kahle Bodenoberfläche, wodurch der Boden mit einer lockeren Sandschicht bedeckt wird. Dem unter dieser Decksandschicht folgenden hellbraunen, etwa 30-40 cm mächtigen Bodenhorizont verleiht ein Minimum an Humus seine Farbtönung. Das Profil wird nie nachhaltig durchfeuchtet, weshalb die chemische Aufbereitung des Muttermaterials nur äusserst langsam vor sich geht. Die braunen Wüstenböden sind deshalb ausnahmslos sandig. Die gelegentliche Befeuchtung durch die Niederschläge reicht gerade zum Lösen von Salzen, doch werden diese bald wieder ausgeschieden. Allgemein reagieren deshalb diese Böden schwach bis stark alkalisch. Unter dem beschriebenen, hellbräunlichen Horizont folgt das lockere Muttermaterial meistens vulkanischen Ursprungs. Die Profile dieser braunen Wüsten bis Halbwüsten erscheinen somit sehr flachgründig und die Bodenbildungsprozesse sind hier ausserordentlich schwach.

An landwirtschaftliche Nutzung dieser Trockengebiete der Anden ist vorläufig nicht zu denken. Die geringe Qualität des Bodens würde kaum eine Bewässerung rechtfertigen.

DISKUSSION DER ERGEBNISSE

Das Vorkommen dieser ausserordentlich unterschiedlichen Bodenausbildungen und Vegetationen in Ecuador ist nur durch die regional sehr grossen Klimaunterschiede zu erklären. Die Klimavariationen in diesem unter dem Aequator gelegenen Land ergeben sich aus den speziellen topographischen Verhältnissen. In Figur 3 ist ein schematischer West-Ost-Querschnitt durch das Land gezeichnet, an dem der Zusammenhang der topographischen Klimaregionen mit dem Bodentyp und der Vegetation verdeutlicht werden soll. Im tropisch warmen, westlichen Andenvorland sind die Boden- und Vegetationsverhältnisse im wesentlichen durch die variierende Niederschlags-

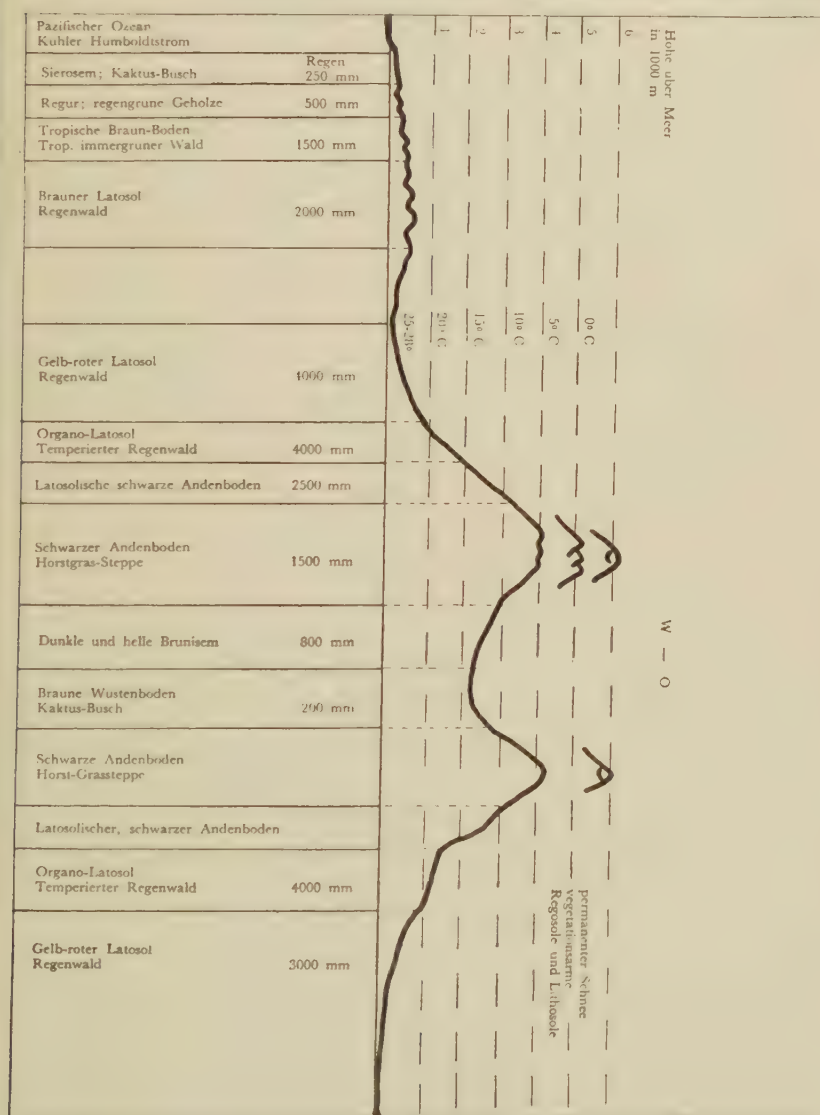
menge beeinflusst. Von der regenarmen pazifischen Küste bis zum ausserordentlich regenreichen Andenfuss wechselt man vom trockenen Sierosem und Regur durch Uebergänge zum immer feuchten gelbroten Latosol. Gleichzeitig wechselt die Vegetationsdecke in auffälligster Weise vom schütterten, kaktusreichen Halbwüstenbusch zum regengrünen Wald, dann zum immergrünen Wald und schliesslich zum undurchdringlichen, palmenreichen Regenwald. Unterschiede im Feuchtigkeitsregime bei ungefähr gleich bleibender hoher Temperatur, vermögen derart grosse Unterschiede in der Boden- und Vegetationsausbildung zu bewirken, dass bei einer Uebersichtsbetrachtung jeder andere Faktor zurücktreten muss. Selbstverständlich können aber auch in diesen tropischen Gebieten bei detaillierten Studien die Einflüsse der Lokaltopographie, der geologischen Unterlage usw. nicht übersehen werden.

Vom Andenfuss bis zu den Andengipfeln erkennt man hauptsächlich den Einfluss der abnehmenden Jahrestemperatur verbunden mit etwas geringeren Niederschlagsmengen. Die kühlere Temperatur bewirkt vor allem eine Zunahme der Humusproduktion. Der Abbau der im Regenwald reichlich anfallenden organischen Substanz ist bei etwas weniger warmer Temperatur bereits leicht gehemmt. Bei der noch kühleren Temperatur der Andengipfel gilt dies noch in vermehrtem Masse. Veränderungen in Temperatur und Feuchtigkeit beeinflussen nicht nur die Humusbildung, sondern ebensosehr die Verwitterungsart und -intensität, sowie die Bildung von Bodenmineralen und Gelen. Dies führt zu völlig verschiedenem Aufbau des Latosolprofils im Gegensatz z.B. zum Schwarzen-Andenboden der Hochlage.

Im Zwischenandentale bestehen spezielle Niederschlagsverhältnisse verursacht durch den Regenschatten der Gebirge. Die festgestellten Unterschiede in Bodenausbildung und Vegetation sind hier als in erster Linie niederschlagsbedingt aufzufassen, wobei es sich um temperierte bis eher kühle Gebiete handelt. Der Uebergang vom Schwarzen-Andenboden zum Brunisem und zum braunen Wüstenboden ist wiederum von auffälligen Veränderungen in der Vegetation begleitet, die deutlich eine Anpassung an zunehmend aridere Verhältnisse erkennen lassen.

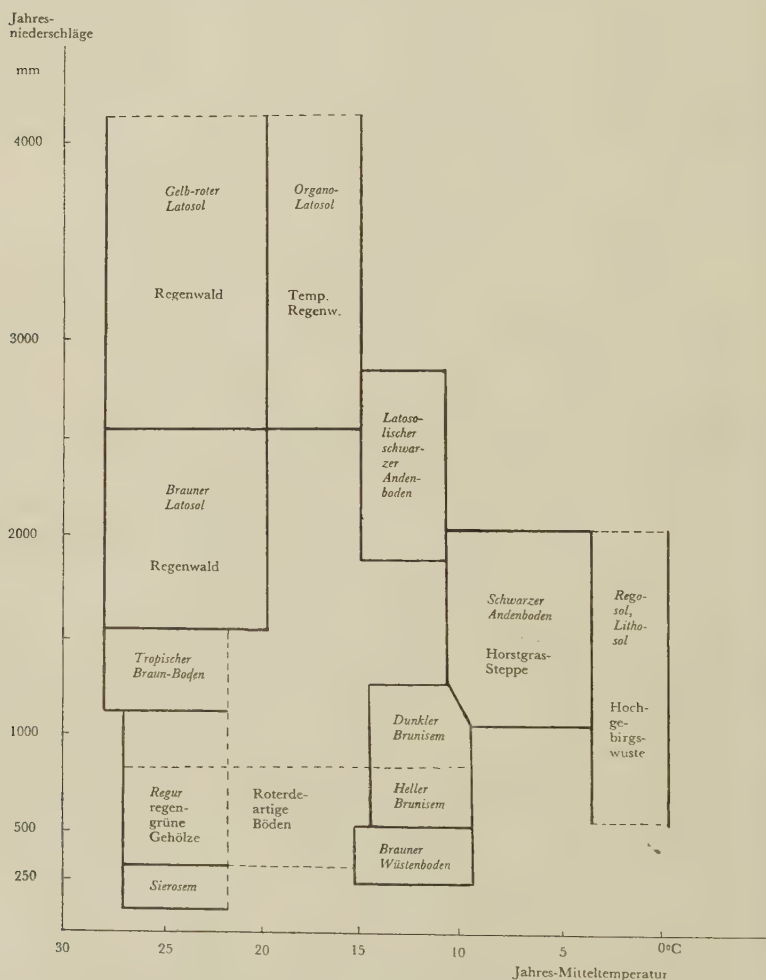
Der Einfluss der Jahresniederschlagshöhe und der Mitteltemperatur auf die Bodenausbildung und die Vegetation, ist in Figur 4 nochmals anhand einer graphischen Darstellung erläutert. Eine

direkte Beziehung zwischen Niederschlagssumme und Mitteltemperatur einerseits und der Boden- und Vegetationsausbildung andererseits, ist in äquatorialen Gebieten eher vorhanden, als in den gemässigten Zonen mit ihren grossen Klimaschwankungen. Die



Figur 3. Schematische Darstellung der Landform Ecuadors und der Beziehung zu Bodentyp und Klima.

Mitteltemperaturen Ecuadors setzen sich aus wenig voneinander abweichenden Einzelwerten zusammen; die Niederschlagssummen können zwar von Jahr zu Jahr ziemlich verschieden sein, jedoch ist die Niederschlagsverteilung einigermassen konstant.



Figur 4. Ecuadors Böden in Beziehung zum Jahresniederschlag und zur jährlichen Mitteltemperatur.

Man erkennt in Figur 4 links in der Senkrechten die Bodentypfolge bei gleichmässig tropisch warmer Temperatur als Funktion variierender Niederschlagsgrösse. Diese Reihe vom Sierosem zum gelbroten

Latosol ist im westlichen Andenvorland Ecuadors in lückenloser Folge vorhanden. Von oben links im Diagramm nach unten rechts haben wir eine durch die gleichzeitig variierende Temperatur und Niederschlagssumme bedingte Folge von Bodentypen. Nämlich der an den äusseren Andenhängen verfolgbare Uebergang vom gelbroten Latosol zum Schwarzen Andenboden.

Die vorliegende Studie gibt bei weitem kein vollständiges Inventar der tropischen Bodentypen, dies lassen auch die im Diagramm der Figur 4 enthaltenen Lücken vermuten. Im besprochenen Gebiet fehlt vor allem das feucht-kühle Klima mit wahrscheinlich podsolierten Böden und das mässig feucht-temperierte Klima mit den entsprechenden Bodentypen.

In Ecuador, einem rein tropischen Land, konnte somit ein enger Zusammenhang zwischen Klimavariationen und der Boden- und Vegetationsausbildung beobachtet werden. Die Erkenntnis dieser Zusammenhänge ist nicht nur wichtig für Zwecke der Boden- und Vegetationskartierung, sie sind ebenfalls von grosser Bedeutung für die Lenkung der land- und forstwirtschaftlichen Entwicklung dieser tropischen Gebiete.

ZUSAMMENFASSUNG

Neun wichtige Bodentypen Ecuadors werden beschrieben; sie lassen sich in Gruppen der Wüstenböden, der schwarzen und braunen Tonböden, der Latosole und der dunkeln Gebirgsböden einreihen. Als Hauptursache für das Vorkommen derart verschiedener Böden sind klimatische Unterschiede erkannt worden. Die Summe der Jahresniederschläge, wie auch die jahreszeitliche Niederschlagsverteilung erreichen Extreme, die sich in den entsprechenden Bodentypen deutlich widerspiegeln. Auch Temperaturunterschiede, bedingt durch wechselnde Höhenlage, beeinflussen Boden- und Vegetationsausbildung in wesentlichem Masse.

SUMMARY

A study of the relation between soil, climate and vegetation of Ecuador.

Nine important soil groups of the territory of Ecuador have been described. They belong to the associations of desert soils, black and brown tropical soils, Latosols, and dark mountain soils. Climatic differences have been recognised as the main reason for these widely varying soil formations. The soil formations reflect clearly the distinctions in annual precipitation and monthly rain distribution. The soil profile and the vegetation cover seem

also to be greatly influenced by differences in the mean annual temperature depending on the altitude above sea level

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EXPLORATORY POT EXPERIMENTS ON SENSITIVENESS OF DIFFERENT CROPS TO SODIUM: D. BARLEY

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INTRODUCTION

The good response of barley to sodium fertilization was already known in England 150 years ago. At this time, according to a communication issued by the Ministry of Agriculture, practical use was already being made of sodium chloride as a fertilizer on the dry, chalky soils of the south-eastern counties ⁴.

Other communications have been published about the favourable effect of common salt (Hartwell and Pember ¹², Wheeler ²⁷) upon barley and, in particular, of low grade potash salts (Wagner²⁶, Byczkowski⁶, Gerlach⁹, Mikulowski-Pomorski and Wojtysiakowa ²¹), in which sodium is an active component.

A characteristic of barley is its very high resistance to injury from salt, and this has become apparent in recent years (1944/45) in the inundated areas of the province of Zeeland, the Netherlands. In practically all these areas the first crop to come up reasonably well was barley which gave the least depleted yield of all crops cultivated (Van den Berg ², Bosma ³). These findings are in agreement with those of Harris ¹¹ and Marshall ²⁰.

The germination experiments carried out by Mulwani and Pollard ²³ demonstrated that barley is more resistant to injury from common salt than the other cereals but less resistant than peas, sugar beet, red clover, mangold, mustard, lucerne and paddy. Probably barley is more sensitive on alkali, than on saline soils (Kelley and Arani ¹⁵).

As to the ability of barley to take up potassium and sodium, opinions expressed in the literature vary and especially wide deviations are found in the content values for the straw. A comparison of the most authoritative papers on this subject ^{1 14 16 26 29} suggest that the potassium-absorbing capacities decrease in the sequence : oats > barley $\gg$ rye > wheat, although according to the same source, the potassium content in the grain is generally highest for barley, followed by rye, oats and wheat.

Information available in the literature on the uptake of sodium is rather scanty. It is fairly certain that both oats and barley possess higher sodium-uptake capacities than wheat and rye. From personal experience we are inclined to attribute a higher sodium-absorbing capacity to barley than to oats.

Byczkowski ⁶ also occasionally found high contents of sodium in barley, especially in the straw. In general, it may be said that, for crops grown on the same field and subjected to identical treatments, the sodium content of the grain of barley is at least as high, probably higher, than that of the grain of oats; the further sequence is: wheat > rye.

On sampling barley at the stage of ear emergence, Goodall ¹⁰ found the largest concentration of potassium in the ears, whereas the highest content of sodium was found in the vegetative parts of the plants (leaves, leafsheaths, and stems).

The three experiments described below form part of a series of similar experiments (some of which have already been published ^{17 18 19}), designed particularly for an investigation into the importance of sodium for certain crops, as well as into the function of sodium in plant life, in general. In this investigation a special point for consideration has been whether sodium should be regarded merely as a substitute for potassium, where the latter is present in insufficient amounts, or as an element having an essential and specific function, irrespective of a sufficiency or a deficiency of potassium.

EXPERIMENTAL SECTION

Three pot experiments were carried out, two on dusarit/glass-sand mixtures in 1943 and 1950, and one on a humic sandy soil in 1943. In the earlier experiments the nitrates of sodium and calcium were

compared; the experimental design and amounts of fertilizers applied (which may be seen from Tables I and II) were the same as described for experiments with oats¹⁸, with the single exception that no $\text{Ca}(\text{OH})_2$ was applied to the soil.

In 1950 a more extensive pot experiment was carried out on mixtures of quartz sand and dusarit of a varying composition. In order to preclude all influence of anions, both cations were applied adsorbed to the admixed dusarit while the nitrogen dressing was given in the form of calcium nitrate to all pots. The design of the experiment is detailed below (C).

A. Barley, in glass pots, on mixtures of dusarit quartz sand (1943)

As in the experiments with oats¹⁸, the development of plants receiving calcium nitrate together with 1 per cent potassium lagged considerably behind those receiving sodium nitrate and the same potassium dosage. No appreciable differences were observable between the plants of the 3 and 8 percentage potassium levels. In the final stage, however, the plants receiving sodium nitrate were better developed at all potassium levels, especially at the 1 and 3 percentage levels.

TABLE I

Barley on dusarit/quartz-sand mixtures: yield data					
Dressing	Grain yield (dry matter, g/pot)	Straw yield (dry matter, g/pot)	Weight of 1000 grains (g)	Length of straw (cm)	Average weight of straw g/cm)
<i>Sodium nitrate</i>					
1% K	12.7 ± 0.24	14.2 ⁵ ± 0.20	50.8	102	0.140
3% K	14.0 ± 0.48	16.3 ± 0.6 ⁵	53.9	111	0.147
8% K	14.2 ± 0.15	17.8 ± 0.06	53.0	111	0.160
<i>Calcium nitrate</i>					
1% K	10.8 ± 0.09	11.7 ± 0.30	43.4	88	0.133
3% K	13.6 ± 0.67	(14.0) ± 0.57	50.7	97	0.146
8% K	14.1 ± 0.20	17.3 ± 0.33	51.4	109	0.159

B. Barley, in glass pots, on humic, sandy soil (1943)

The condition of the crop was better on soil than on dusarit. The differences in development were, in general, very small and as in Experiment A, the group receiving calcium nitrate lagged behind

when potassium dressing was omitted. With the addition of potassium chloride, however, the development of the plants receiving calcium nitrate was a little better than that of the plants dressed with Chilean nitrate.

TABLE II

Barley on humic sandy soil: yield data					
Dressing	Grain yield (dry matter, g/pot)	Straw yield (dry matter, g/pot)	Weight of 1000 grains (g)	Length of straw (cm)	Average weight of straw (g/cm)
<i>Chilean nitrate</i>					
no KCl	15.1 ⁵ ± 0.21	19.5 ± 0.20	54.0	104	0.188
300 mg KCl	15.1 ± 0.36	20.5 ± 0.47	54.9	105	0.195
700 mg KCl	14.7 ± 0.31	21.6 ± 0.89	54.7	109	0.198
<i>Calcium nitrate</i>					
no KCl	13.7 ⁶ ± 0.30	16.2 ± 0.28	52.0	96	0.152
300 mg KCl	15.1 ± 0.12	20.0 ± 0.29	53.5	108	0.185
700 mg KCl	15.3 ± 0.18	21.8 ± 0.65	55.0	110	0.198

In both experiments better results were obtained with NaNO_3 than with $\text{Ca}(\text{NO}_3)_2$ at the lower potassium levels, but at the higher potassium levels the differences between the effects of the two nitrogenous fertilizers all lie within the experimental error.

In view of the fact that the soil used in Experiment B was rich in sodium¹⁸ the results give no decisive answer to the question whether sodium acts as a replacement of potassium or whether it is capable of influencing favourably the yields even when a sufficiency of potassium is available.

In Experiment A, sodium was excluded as far as possible and the supply was limited to the small amounts released by the quartz sand and possibly present in the demineralized water used. The results of this experiment do not indicate that for barley sodium has a specific and essential function in the attainment of maximal yields but only suggests a replacement effect.

C. Barley, in glass pots, on mixtures of dusarit/quartz sand (1950)

The quartz sand was pretreated with warm, concentrated hydrochloric acid and subsequently rendered chlorine free with demineralized water. The experiment was subdivided into three series in which the univalent

ions (potassium and sodium) constituted 10, 20 and 40 per cent of the total amount of adsorbed cations. To 2.4 kg quartz sand each pot received a total of 100 g dusarit which represented 200 me adsorbed cations. In all pots the magnesium level was held at 6 per cent, and the various totals of K + Na + Mg (were made up with calcium) to 100 per cent. The pH of the dusarit suspension was 6.2.

The detailed experimental design was as shown in Table III.

TABLE III

Variations in the ratio of potassium to sodium				
Group	% K	% Na	Ratio K:Na	Number of replications
<i>I. Pots containing 10% of the adsorbed ions as K + Na</i>				
1	10	0	(10): 0	6
2	9.5	0.5	19 : 1	6
3	8.75	1.25	7 : 1	6
4	7.5	2.50	3 : 1	6
5	5	5	1 : 1	4
6	2.5	7.5	1 : 3	4
7	0	10	0 : (10)	4
<i>II. Pots containing 20% of the adsorbed ions as K + Na</i>				
8	20	0	(20): 0	6
9	19.5	0.5	39 : 1	6
10	19	1	19 : 1	6
11	18.5	1.5	12 : 1	6
12	17.5	2.5	7 : 1	6
13	15	5	3 : 1	4
14	10	10	1 : 1	4
15	7.5	12.5	1 : 5/3	4
16	5	15	1 : 3	4
17	2.5	17.5	1 : 7	4
18	0	20	0 : (20)	4
<i>III. Pots containing 40% of the adsorbed ions as K + Na</i>				
19	40	0	(40): 0	6
20	39.5	0.5	79 : 1	6
21	39	1	39 : 1	6
22	38.5	1.5	26 : 1	6
23	38	2	19 : 1	6
24	37	3	12 : 1	4
25	36	4	9 : 1	4
26	35	5	7 : 1	4
27	30	10	3 : 1	4
28	20	20	1 : 1	4
29	10	30	1 : 3	4
30	0	40	0 : (40)	4

On top of the dusarit/quartz sand mixtures in the pots a germination layer of 200 g sand was placed. Water was supplied to 60 per cent of the waterholding capacity. The technique of our pot experiments can be found in previous papers ^{17 18 19 25}.

Basic dressing: 540 mg $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$; 40 mg $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$; 50 mg $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$; 15 mg FeCl_3 ; 5 mg borax.

Nitrogen: 300 mg N in the form of $\text{Ca}(\text{NO}_3)_2$, applied in three equal portions.

Growth observations. In the first month of development no appreciable differences were observable either between the plants of the various series or between the plants within a series. Later, in all series the plants which received no potassium began to lag behind the others, retardation being more pronounced in those receiving 40 per cent sodium (Series III) than in those receiving 20 or 10 per cent. The signs of potassium deficiency became gradually more pronounced. These plants were darker in colour and reached the stage of ear emergence two weeks after the others.

However, the lowest amount of potassium in the complex was sufficient to prevent deficiency symptoms.

Regarding the other treatments it was observed that all plants of Series III were of a lighter green and that yellowing of the lower leaves occurred, especially as the sodium percentage increased from 3 to 40 per cent.

In some cases there were weak indications that the plants receiving "intermediate" K:Na ratios developed better, but the differences were not really striking. It was established, however, during a period of warm weather, that less evaporation of moisture occurred from the plants receiving a high sodium level in the complex (40 percentage series).

The results of this experiment (Table IV) can best be arranged and discussed point by point:

1. The level of the univalent ions ($\text{K} + \text{Na}$) has a certain influence on the trend of the yield curves but this influence is irregular and does not give rise to systematic and similar changes in the relative position of the curves. A depressive influence upon the yield is only seen in Series III (40% $\text{K} + \text{Na}$) with the lower potassium, sodium ratios in the complex. An explanation for the absence of a systematic difference in the effect of the total level of univalent ions is given below.

TABLE IV

Barley on dusarit/quartz-sand mixtures (1950): yield data

Group	K : Na ratio of dusarit	Grain yield (dry matter, g/pot)	Straw yield (dry matter, g/pot)	Weight of 1000 grains (g)	Length of straw (cm)	Average weight of straw (g/cm)
<i>Series I. 10% of the adsorbed ions (= 10 me) as K + Na</i>						
1	(10): 0	14.11 $\pm$ 0.29	16.23 $\pm$ 0.43	35.27	86.3	0.188
2	19 : 1	13.82 $\pm$ 0.32	15.51 $\pm$ 0.27	34.48	84.2	0.184
3	7 : 1	13.73 $\pm$ 0.42	16.53 $\pm$ 0.24	35.66	83.3	0.199
4	3 : 1	14.26 $\pm$ 0.18	16.04 $\pm$ 0.21	37.04	81.7	0.196
5	1 : 1	14.04 $\pm$ 0.19	16.49 $\pm$ 0.37	34.76	81.3	0.203
6	1 : 3	13.62 $\pm$ 0.32	16.74 $\pm$ 0.47	35.92	80.8	0.207
7	0 : (10)	6.75 $\pm$ 0.19	12.70 $\pm$ 0.042	21.84	40.0	0.318
<i>Series II. 20% of the adsorbed ions (= 20 me) as K + Na</i>						
8	(20): 0	14.53 $\pm$ 0.18	16.90 $\pm$ 0.14	36.98	81.0	0.208
9	39 : 1	13.93 $\pm$ 0.080	16.04 $\pm$ 0.21	36.67	81.7	0.196
10	19 : 1	(13.86) $\pm$ 0.27	16.25 $\pm$ 0.19	36.63	82.6	0.197
11	12 : 1	13.70 $\pm$ 0.25	15.30 $\pm$ 0.29	36.09	83.2	0.184
12	7 : 1	13.93 $\pm$ 0.47	16.51 $\pm$ 0.022	36.08	84.8	0.195
13	3 : 1	14.00 $\pm$ 0.26	16.04 $\pm$ 0.25	37.55	85.8	0.187
14	1 : 1	14.16 $\pm$ 0.45	17.44 $\pm$ 0.22	42.14	(81.7)	0.214
15	1 : 5/3	14.62 $\pm$ 0.34	17.27 $\pm$ 0.43	36.90	86.3	0.200
16	1 : 3	14.41 $\pm$ 0.35	17.21 $\pm$ 0.32	36.94	(83.3)	0.207
17	1 : 7	14.45 $\pm$ 0.28	17.52 $\pm$ 0.27	38.84	87.0	0.201
18	0 : (20)	5.16 $\pm$ 0.54	13.14 $\pm$ 0.27	25.41	43.8	0.300
<i>Series III. 40% of the adsorbed ions (= 40 me) as K + Na</i>						
19	(40): 0	14.13 $\pm$ 0.21	16.96 $\pm$ 0.44	40.60	77.2	0.220
20	79 : 1	13.69 $\pm$ 0.24	16.49 $\pm$ 0.24	35.73	80.0	0.206
21	39 : 1	14.15 $\pm$ 0.24	15.83 $\pm$ 0.21	38.35	79.8	0.199
22	26 : 1	14.28 $\pm$ 0.17	15.97 $\pm$ 0.24	37.38	77.5	0.206
23	19 : 1	14.91 $\pm$ 0.29	15.81 $\pm$ 0.25	38.13	79.0	0.200
24	12 : 1	14.74 $\pm$ 0.21	16.31 $\pm$ 0.14	38.20	75.8	0.215
25	9 : 1	14.97 $\pm$ 0.30	15.94 $\pm$ 0.25	38.59	80.8	0.198
26	7 : 1	14.45 $\pm$ 0.22	16.91 $\pm$ 0.22	38.12	79.8	0.212
27	3 : 1	14.03 $\pm$ 0.37	15.87 $\pm$ 0.17	37.61	81.0	0.196
28	1 : 1	13.02 $\pm$ 0.27	15.45 $\pm$ 0.25	34.73	78.3	0.198
29	1 : 3	12.82 $\pm$ 0.080	15.22 $\pm$ 0.45	35.61	78.3	0.195
30	0 : (40)	9.28 $\pm$ 0.56	12.21 $\pm$ 0.26	33.15	54.5	0.224

2. The ratio between potassium and sodium also appears to have been of secondary importance as far as yields are concerned. Only when the 75 percentage level of sodium is exceeded (in Series II, above 87½ per cent sodium) does the sodium show a general, depressive influence, and, in fact, this influence reveals itself only when potassium is omitted entirely from the complex. The relevant

plants displayed characteristic potash-deficiency symptoms (groups 7, 18 and 30).

3. A more detailed analysis of the yields within the potassium/sodium ratio range, ∞ to 1 : 7, reveals only a few indistinct indications of a systematic influence exerted by these ratios. It is,

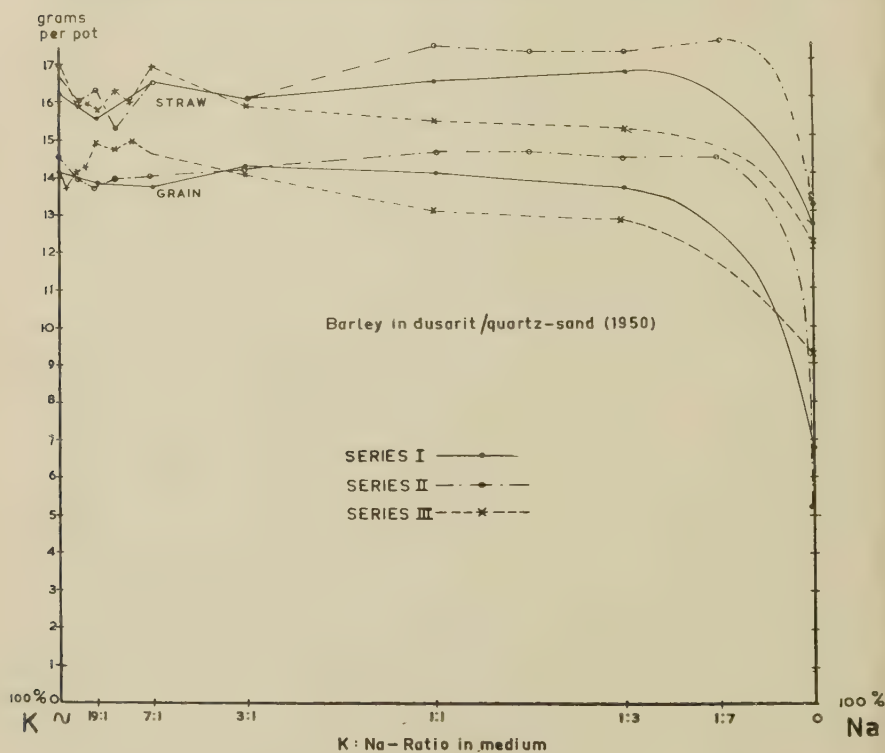


Fig. 1. Dry-matter yields of barley in dependence on K:Na ratios.

however, striking that in all three series, the straw yield (Fig. 1) is slightly decreased by the first application of sodium, reaches a maximum with a potassium/sodium ratio of 7 : 1, and again decreases with a ratio of 3 : 1; thereafter, in Series I and II, the highest yields of straw (significant!) are obtained with the ratios 1 : 1 to 1 : 3 and 1 : 1 to 1 : 7, respectively.

The trend of the grain yields (Fig. 1) is less regular, although here again the first minimum is present while in Series I and II a maximum (only very slightly pronounced) is found. In Series III, the highest yield is obtained with ratios between 19 : 1 and 7 : 1.

Without wishing to attach too much weight to these differences, we still cannot regard them as accidental. This phenomenon, namely that the application of one of the components causes an original decrease in yield and only later gives rise to a definitive increase, has been previously observed in experiments in connection with the potassium sodium effect (see De Willigen²⁸). The analyses of this experiment are given in Table V.

4. From the above analyses a fairly regular trend in the percentage of potassium, sodium, calcium, magnesium and nitrogen is seen. In the straw, the potassium sodium ratios practically follow the compositions of the complex. This is particularly so in Series I, but somewhat less noticeable in Series II and III (see Fig. 2).

In the grain, the potassium sodium ratio tends to remain fairly constant up to a ratio of 1 : 1 in the substrate. With higher proportions of sodium in the complex, however, the composition of the grain takes a different course (Fig. 2).

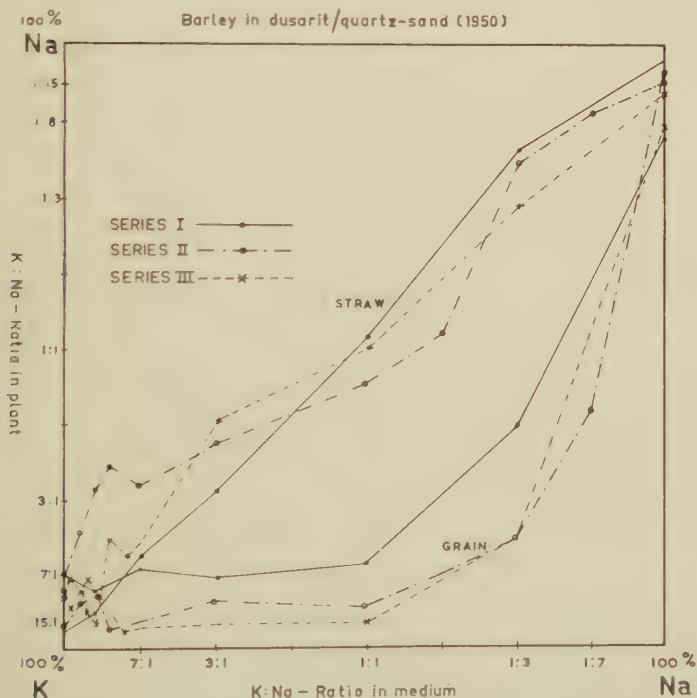


Fig. 2. Correlations between the ratios of K:Na in medium and plant (in me).

TABLE Va

Analyses of barley on dusarit/quartz-sand mixtures (1950). Straw							
Group	K : Na ratio of dusarit	Ash %	Contents in milli-equivalents per 100 g of dry matter				
			K	Na	Ca	Mg	Sum
<i>Series I. 10% of the adsorbed ions (= 10 me) as K + Na</i>							
1	(10): 0	7.8	105.8	3.5	18.4	11.6	139.3
2	19 : 1	7.9	89.2	5.5	21.5	10.4	126.6
3	7 : 1	7.2	78.3	14.5	16.7	9.8	119.3
4	3 : 1	6.6	60.0	21.5	16.7	9.3	107.5
5	1 : 1	6.0	41.8	44.5	14.5	11.4	112.2
6	1 : 3	5.7	19.9	75.8	15.7	11.9	123.3
7	0 : (10)	9.8	3.4	152.8	10.9	16.6	183.7
<i>Series II. 20% of the adsorbed ions (= 20 me) as K + Na</i>							
8	(20): 0	9.0	78.7	11.3	18.6	7.2	115.8
9	39 : 1	9.4	72.8	17.8	20.7	9.4	120.7
10	19 : 1	9.3	69.7	25.6	18.4	7.5	121.2
11	12 : 1	9.0	72.8	31.7	19.0	7.8	131.3
12	7 : 1	8.4	58.6	22.1	16.5	5.8	103.0
13	3 : 1	8.1	63.1	33.7	17.2	4.3	118.3
14	1 : 1	7.5	47.3	37.4	15.4	6.0	106.1
15	1 : 5/3	7.9	44.8	49.1	20.6	8.2	122.7
16	1 : 3	7.2	26.6	81.7	17.2	6.5	132.0
17	1 : 7	6.8	12.5	102.1	17.3	6.6	138.5
18	0 : (20)	11.9	6.6	170.0	26.4	12.1	215.1
<i>Series III. 40% of the adsorbed ions (= 40 me) as K + Na</i>							
19	(40): 0	9.9	90.8	10.5	8.8	2.2	112.3
20	79 : 1	10.3	94.0	13.0	10.7	4.7	122.4
21	39 : 1	10.0	86.5	9.9	9.5	3.5	109.4
22	26 : 1	9.8	87.9	6.4	7.3	4.6	106.2
23	19 : 1	9.8	79.3	3.8	9.8	3.5	96.4
24	12 : 1	10.0	88.4	20.2	8.7	3.5	120.8
25	9 : 1	9.7	92.2	17.3	9.3	4.1	122.9
26	7 : 1	9.7	73.6	16.0	9.8	2.7	102.1
27	3 : 1	9.0	59.5	36.5	8.1	1.8	105.9
28	1 : 1	8.6	45.3	45.1	8.4	2.6	101.4
29	1 : 3	8.2	21.1	56.8	9.4	1.4	88.8
30	0 : (40)	9.9	11.9	148.3	12.1	1.0	173.3

5. It is noteworthy that the difference in K + Na level (in Series I, II and III) has had practically no influence upon the composition of the plant. This appears from the following averages (per series) for the total recovery per pot, of nitrogen, potassium

TABLE Vb

Analyses of barley on dusarit/quartz-sand mixtures (1950). **Grain**

Analyses of barley on dusarit/quartz-sand mixtures (1950). Grain							
Group	K : Na ratio of dusarit	Ash %	Contents in milli-equivalents per 100 g of dry matter				
			K	Na	Ca	Mg	Sum
Series I. 10% of the adsorbed ions (= 10 me) as K + Na							
1	(10) : 0	2.2	19.8	2.9	3.5	7.4	33.6
2	19 : 1	2.5	20.5	2.1	3.2	7.3	32.9
3	7 : 1	2.2	12.7	2.0	3.9	6.4	25.0
4	3 : 1	2.1	11.4	1.6	3.8	8.1	24.9
5	1 : 1	2.1	10.7	1.8	2.7	7.3	22.5
6	1 : 3	2.7	3.1	1.8	2.9	7.9	15.7
7	0 : (10)	2.8	2.6	14.6	4.4	10.4	32.0
Series II. 20% of the adsorbed ions (= 20 me) as K + Na							
8	(20) : 0	2.2	14.0	0.6	1.6	8.1	24.3
9	39 : 1	2.3	16.8	1.5	1.5	8.3	28.1
10	19 : 1	2.2	14.5	1.4	1.9	8.6	26.4
11	12 : 1	2.2	14.7	0.6	1.7	8.0	25.0
12	7 : 1	2.3	13.6	0.7	1.3	7.5	23.1
13	3 : 1	2.3	15.7	1.5	1.5	7.4	26.1
14	1 : 1	2.1	15.1	1.2	1.7	9.3	27.3
15	1 : 5/3	2.2	13.6	2.0	1.7	8.0	25.3
16	1 : 3	2.1	12.0	2.7	1.6	9.2	25.5
17	1 : 7	3.1	8.8	5.9	1.6	8.4	24.7
18	0 : (20)	3.5	9.4	14.9	2.4	10.7	37.4
Series III. 40% of the adsorbed ions (= 40 me) as K + Na							
19	(40) : 0	2.2	16.6	2.1	3.1	5.7	27.5
20	79 : 1	2.2	16.8	1.3	1.7	5.9	25.7
21	39 : 1	2.3	17.8	2.0	1.4	6.4	27.6
22	26 : 1	2.3	17.7	2.4	2.3	4.9	27.3
23	19 : 1	2.3	18.0	1.9	2.0	5.7	27.6
24	12 : 1	2.2	17.6	1.0	2.1	4.8	25.5
25	9 : 1	2.2	17.5	0.6	2.1	5.7	25.9
26	7 : 1	2.3	17.8	0.7	2.0	5.2	25.7
27	3 : 1	2.3	17.9	0.8	2.2	5.5	26.4
28	1 : 1	2.4	15.8	0.7	2.3	5.6	24.4
29	1 : 3	2.6	12.2	2.8	2.2	4.7	21.9
30	0 : (40)	2.7	9.5	18.5	3.0	6.2	37.2

plus sodium, and the four cations (K + Na + Ca + Mg) together:

Recovery per pot, in me				
Series	K + Na level	N	K + Na + Ca + Mg	K + Na
I	10%	16.2	23.6	17.8
II	20%	16.8	24.4	18.7
III	40%	16.5	21.2	18.4
Mean		16.5	23.1	18.3

If, on the basis of the salts applied in the basic dressing, it is accepted that the uptake of phosphate, sulphate and chloride is together 5 to 6 me, the uptakes of anions and cations are then found to be practically equivalent; it appears, therefore, that the available amount of anions has acted as a limiting factor for the uptake of cations. At the same time, it is now understandable why there was practically no difference in the effect on yield between the three different levels of univalent ions (see point 1 above).

6. The nitrogen content of the straw appears to be independent of the level of univalent ions (means of 0.34⁵, 0.35⁵, and 0.35 per cent N, for Series I, II and III, respectively). The content of the grain displays a weak tendency to decrease, but the differences are not significant (means of 1.34, 1.33⁵ and 1.27 per cent N, for Series I, II and III, respectively). There is no evidence of a uniform influence of the potassium/sodium ratio upon the nitrogen content.

The conclusion drawn from the results is that throughout a wide range of ratio potassium and sodium have acted upon barley as equally valuable nutrient elements. It is true that at the 20 and 40 percentage levels there is a slight tendency towards higher yields from intermediate potassium/sodium ratios but the extent of the extra yield is not sufficient to justify the conclusion that sodium has an independent (essential) function. In the discussion which follows, it will, therefore, be accepted that the results of this experiment suggest for sodium only a potassium-replacing action. Before drawing definitive conclusions it would certainly be desirable to apply greater variations of nitrogen, and possibly, also of phosphate nutrition, in conjunction with a normal potassium and sodium level (10 per cent), as the impression is gained that in this experiment the anion nutrition has acted as a limiting factor.

DISCUSSION

In a preceding paper in this series ¹⁸ a more critical analysis of the significance of sodium in plant growth was attempted. This was based upon a discussion of the type of yield curves obtained from pot experiments designed to investigate the interaction of sodium and potassium. A study of the experimental data relevant to oats available in the literature strongly suggests that, although the

respective functions of sodium and potassium are no doubt related, sodium does not, or not exclusively, act in a potassium-replacing capacity but exercises also an independent yield-increasing effect which is exerted even in the presence of sufficient potassium.

A similar investigation of the literature for information on pot experiments with barley is less rewarding: relatively few data are available and in consequence, the resulting picture of the nature of the sodium effect upon barley is less well-defined than that for oats (Table VI).

TABLE VI

Year	Author	Type of experiment	K/Na replace- ment	Inde- pendent effect of sodium
1898	Hellriegel <i>et al</i> ¹³	B† Sand cultures (2 expts.)	+	
1901	Gerlach ⁹	A†† Sandy soil		+
1902	Doll ⁸	B Sand/soil cultures		+
1904	Damseaux ⁷	B Sand cultures	+ *	
1906	Pfeiffer <i>et al</i> ²⁴	A Sand cultures		+
1938	Mikulowski-Pomorski and Wojtysiakowa ²¹	A Soil cultures (2 expts.)		+
1942	Mullison and Mullison ²²	B Water cultures		+
—	Present paper	A Soil cultures	+ **	
—	Present paper	A Sand/dusarit cultures	+	
—	Present paper	B Sand/dusarit cultures	+	

† Experiments with increasing doses of potassium with the addition of a constant amount of sodium.

†† Experiments with a constant number of equivalents of potassium plus sodium but with various ratios of these elements. Compare Ref.¹⁸.

* A very simply designed experiment to which little value can be attached.

** In this experiment the medium itself contained considerable amounts of sodium (200 mg exchangeable Na per pot).

In further explanation of this table, the following information is given. Hellriegel *et al.* carried out two experiments with chlorides in 1892 and 1894, which are suitable for the present purpose; the available details of other experiments by the same research workers, made in 1893 and 1895, are too incomplete to be of value here.

In Gerlach's experiments comparison was made between the effects of progressively increasing doses of "concentrated potash salt" (probably muriate of potash 40%) with and without the addition of sodium chloride. The ratio potash salt / sodium chloride was constant throughout.

In the experiments carried out by Doll both chlorides and sulphates were used. Whilst 50 per cent potassium chloride plus 50 per cent sodium chloride (presumably equivalent amounts) resulted in a pronounced increase

in yield in relation to potassium chloride alone, no such increase was apparently obtained with the sulphate form of sodium.

Damseaux' experiment was greatly simplified. It is probable that he applied equal quantities of potassium and sodium salts and corresponding mixtures (50 : 50) which were not computed on an equivalency basis. The type of soil and the forms of potassium and sodium employed are not mentioned.

Pfeiffer *et al.* applied potassium and sodium as chlorides.

Mikulowski-Pomorski and Wojtysiakowa investigated the influence of the addition of sodium chloride to potassium chloride, potassium sulphate and kainite, respectively, and of the addition of sodium sulphate to kainite and Langbeinite.

Mullison and Mullison (Experiment B, page 638, of the relevant publication) used potassium plus sodium (in chloride form) in a constant number of parts per million; from a comparison of the relevant curves for the combined effect of K + Na with that of potassium alone, it may be seen that sodium, even with the maximum potassium activity, exercises a pronounced independent effect.

Mention of sodium analyses is made only by Doll and Pfeiffer *et al.*

The above summary does still not justify the drawing of more definite conclusions in explanation of the effect of sodium upon barley.

For a closer analysis of the experiments in Table VI the first point to be considered is the form in which sodium was applied. The supposition might be advanced that, with barley, the chloride form of sodium is more active than the nitrate form. In all five of the experiments represented in the column "Independent effect of sodium" the chloride form was employed, while in three of the five cases represented under "K Na replacement", the nitrate form was applied. In practice also, the particular activity of low-percentage potash salts in relation to barley is recognised, a fact which led even Wagner to the conclusion that sodium chloride is essential for maximal yields of barley.

At first sight it is not very probable that the contrariety of the results rests upon a difference in the effects of different salts in view of the fact that, in general, nitrates are physiologically more active than chlorides — this applies equally to both potassium and sodium*.

* In still unpublished field experiments with barley conducted by this laboratory, a pronounced activity attributable to sodium in the nitrate form was found, even when potash was amply supplied. In these more practical experiments, quite apart from the

Nevertheless, the possibility of interaction with chloride cannot be ruled out entirely.

In view of the findings of Broyer *et al.*⁵, consideration might well be given in future physiological experiments, to the possibility that chlorine is an essential element for the plant and that certain functions of sodium can be fully effective only when adequate amounts of chlorine are present.

Sodium, whether proffered to the plant in the nitrate, phosphate or sulphate form, must for the most part be bound in the organism, to the protoplasm. Nitrate, phosphate and sulphate can all be assimilated and embodied into the organic matter, thus leaving the sodium deprived of oppositely charged ions. In contrast, sodium as sodium chloride can form a component of the cell sap of the vacuole and there, *inter alia*, exercise osmotic effects.

Leaving aside, for the moment, the idea of the existence of soluble sodium salts of organic acids, it may be expected that the chloride form will exercise an effect which is clearly distinguishable from those of the other forms. For this reason, the presence of a certain amount of chloride in physiological investigations into the effect of sodium on barley may well be desirable and, indeed indispensable if an answer is to be obtained to the question whether sodium has a potassium-replacing or essential function with this crop.

SUMMARY

The effect of sodium on barley has been investigated by means of three pot experiments, of which one was on a humic sandy soil and two on an artificial soil complex (dusarit/quartz-sand mixture).

In two of these experiments the effect of sodium – as nitrate of soda – was studied by comparison with calcium nitrate. At low potassium levels sodium was found to exercise a positive effect, but with an ample supply of potassium no differences between the effects of the two nitrate fertilizers were observed.

In the third experiment a wide variation in the potassium and sodium levels was introduced by the application of these elements adsorbed to dusarit, all treatments receiving nitrogen in the form of calcium nitrate. Little influence was exercised by the total level of monovalent ions (10, 20

proper function of sodium, consideration should be given to the physiological alkaline effect of sodium nitrate upon acid soils. However, it may also be of importance that in these experiments the potassium was applied in the chloride form.

and 40 per cent respectively, of the adsorbed bases). Three-quarters, or possibly seven-eighths of the potassium was found to be replaceable by sodium without causing significant changes in the yields of grain and straw.

From a survey of the available literature it cannot yet be concluded whether the importance of sodium for barley is limited to a beneficial effect resulting from its mere replacement of potassium, when too little of the latter is available, or whether this importance may be regarded as essential in the sense that sodium has a yield-increasing effect, even in the presence of a sufficiency of potassium.

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RELATIONS BETWEEN THE POTASH REQUIREMENTS OF CROPS AND METEOROLOGICAL CONDITIONS

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INTRODUCTION

Experience has shown that the growth response of crops to variations in potash supply varies from year to year. It is obvious that this variable behaviour is attributed to differences in weather conditions.

Russell¹⁰ found a negative correlation between the number of hours of sunshine during the period July–October and the depression in the yield of potatoes when application of potash was omitted. The effect of sunshine decreases with adequate applications of potash. This conclusion is based on few data. Russell and Watson¹¹ found in the case of barley that the availability of soil potash was lower and applications of potash were more effective in dry, sunny years. It proved to be more probable that this difference was due to the decreased humidity of the soil than to the excess of sunshine.

In a comparison of marine clay soils having a high level of available potash with river clay soils having a low level of available potash Ferrari² found a clear correlation between yields and weather conditions for the latter kind of soil but not for the former. This might be expected if weather conditions affect the availability of potash as was suggested by this author.

Differences in response to applications of potash may be associated with variations in the moisture content of the soil. In a review of the literature Richards and Wadleigh⁹ mention several instances where the uptake of potash from the soil was promoted by higher soil humidity. Ferrrari³ has found that statistically the potash

content of grass grown on sandy soil with a moderate water supply is higher than on soil with a very low water table. He found the reverse to be the case with very humid soil. The latter agrees with the decreased absorption of potash by sugar beet observed by Larson ⁶ on soils with a very high moisture content. He attributed this to the low oxygen content of these soils.

Schuffelen and Middelburg ¹² conclude on the basis of Donnan-equilibrium considerations, that there will be increased solubility of potassium and decreased solubility of magnesium as soil humidity increases. This has been confirmed experimentally ¹³.

Recently Dijkshoorn and 't Hart ¹ have shown that the cationic content of perennial ryegrass grown under controlled temperature conditions is largely governed by temperature. The potassium content especially increases or decreases considerably after a rise or fall in temperature. These results are in accordance with the field observations of Kemp and 't Hart ⁵. The changes observed are closely correlated with the incidence of grass tetany. Hoagland and Broyer ⁴, working with excised barley roots, had earlier found similar temperature effects.

EXPERIMENTAL

The results from an experimental field, used for the investigation of the effects of potash application, cropped continuously with the same four crops in rotation over a period of 15 years have enabled us to study the relation between the response to potash and weather conditions.

For the investigation of such relationships a suitable general index of weather conditions must be used. Such an index may be the number of rainless days (or days with less than 1 mm of rain); this, according to Post ⁸, characterizes the type of weather satisfactorily. Data of this kind were available for the meteorological station at Zoutkamp which is 6 km from the experimental field. This index is much more suitable than rainfall in mm, since the latter is strongly affected by heavy showers. A further analysis of the influence of meteorological conditions has not been undertaken, as the available data are too few for a partial regression analysis to be made.

Effective indications of the potash requirements of crops are

the differences between yields in the presence or absence of heavy applications of potash, and also the decrease in under-water-weights* of potato tubers after heavy applications of potash, the latter being an index both for dry matter and potash content of the tubers.

The meteorological data for the period May 1st-July 31st were used in the first instance. This period coincides more or less with the growing period of the crops. Whether other periods are more suitable will also be considered.

The relationships between weather conditions and crop response to potash applications are presented graphically and also as correlation coefficients, even though the statistical requirements of a normal distribution are not fulfilled.

The experimental field (Pr 201 at Pieterzijl) is situated in the north of the Netherlands, exactly 20 km north-west of the city of Groningen. It was laid out in 1935 and was continued until 1949. The soil is a light marine clay soil, reclaimed in 1453, still containing 2.3% CaCO_3 but rather deficient in potash.

Potatoes, canary grass, beans and spring wheat were grown simultaneously and in rotation on four adjacent strips of the field. Potash was applied as sulphate of potash to plots replicated three times, in quantities corresponding with 0, 40, 80, 120, 180, 300 and 480 kg K_2O per ha: in the first year the highest amounts were only 240 and 300 kg. The quantities applied were always more than sufficient for the attainment of optimum yields but not high enough to guarantee a minimum value for the under-water-weight of potatoes with certainty.

RESULTS

Apart from the first year the cumulative effect of annual applications of potash has been studied. After some years an almost constant level was reached at each level of potash application. Therefore the results obtained in those years are comparable among themselves. This probably does not hold completely for the second and third years when constant levels had not yet been reached. The effect of a somewhat too low level may have been largely

* The under-water-weight is determined by weighing 5 kg of tubers under water. It is an index of the specific weight.

eliminated by the dominating effect of the annual application of potash so that only the results of the first year have been omitted from the calculations. It has not been noticed that during the experiment the potash requirements increased in the case of the plots not receiving a potash dressing. For this reason the first year values for the K_2O -contents of the crops and the under-water-weight of potatoes on plots not receiving potash are not omitted. The yield of grain could not be determined in 1944.

The average results of all years for this fertilizing experiment are presented in Fig. 1. There is a considerable response by beans,

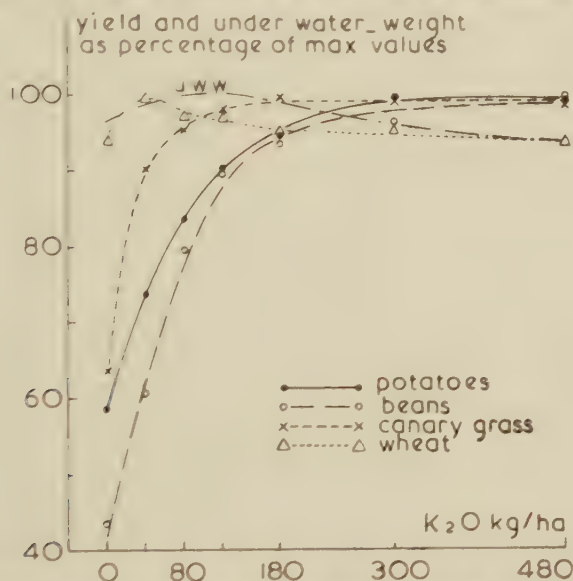


Fig 1 Relation between the level of annual potash application and the average yields of potatoes, spring wheat, beans and canary grass, and the under-water-weights u.w.w. of potatoes (12-14 years). Maximum values are rated at for potatoes (tubers) 100% = 379 q/ha; for wheat (grain) 100% = 33.8 q/ha; for beans (seed) 100% = 31.4 q/ha; for canary grass (grain) 100% = 27.5 q/ha; for under water weight 100% = 49.3 grammes.

potatoes and canary grass. The yield of canary grass reaches a maximum at a rather moderate potash level. The slight increase in wheat yield at the lowest level of potash application is followed by decreasing yields at higher levels. The under-water-weight of potatoes also shows increases at the lower levels of application which are followed by decreases at the higher levels of application.

1. Potatoes

The relation between the number of rainless days and the yields obtained with the highest level of potash application and in the absence of potash application is shown in Fig. 2. From the left-hand parts of the curves it appears that the yield was markedly lower in

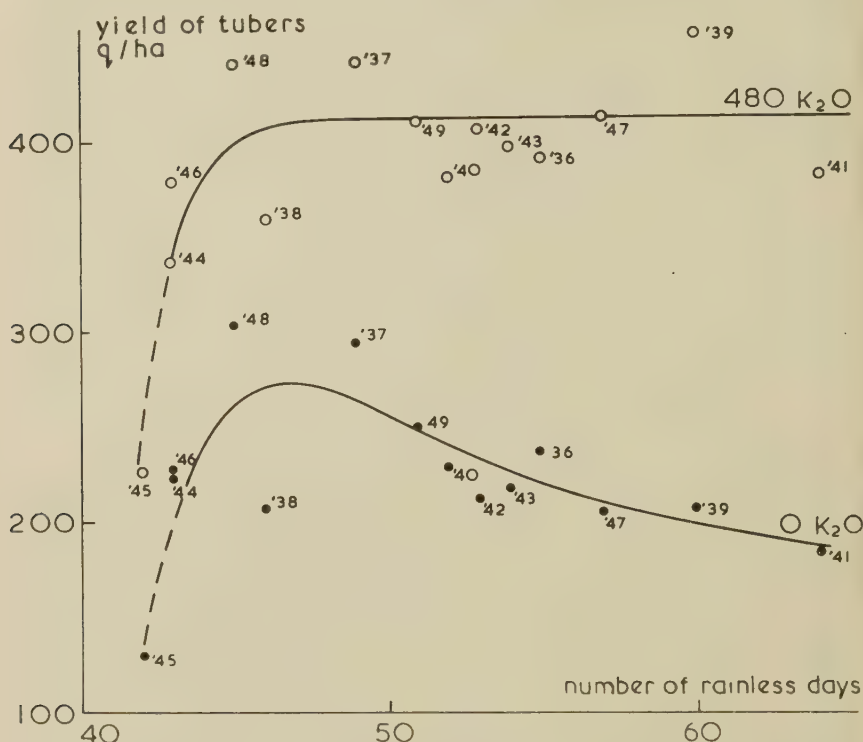


Fig. 2. Relation between the number of rainless days (May-July) and the yield of potato tubers in the presence and absence of heavy applications of potash (480 and 0 kg K₂O per ha).

a very wet year. However, this result does not agree with Russell's¹⁰ observation that the decreased yield (in quintals/ha*) is more pronounced in the absence of potash application than when there are ample dressings of potash. Only relatively as a percentage of the yield obtained when potash is applied, is the yield, in the absence of potash application, in the very wet year 1945 somewhat

* 1 quintal = 100 kg.

lower than in other years. In dry years the yields obtained when potash is applied do not vary appreciably. The yields in the absence of potash application decrease as the number of dry days increases. The difference is thus greatest in dry years.

For comparison of absolute differences between the yields for different years the unfavourable year 1945, with an abnormally low yield, is less suitable and not comparable with the others. Therefore, relative differences will also be taken into consideration.

This positive relation between the maximum increase of the yield of tubers due to potash dressing and the number of rainless days is convincing (Fig. 3). The correlation coefficient (Table I) is 0.84

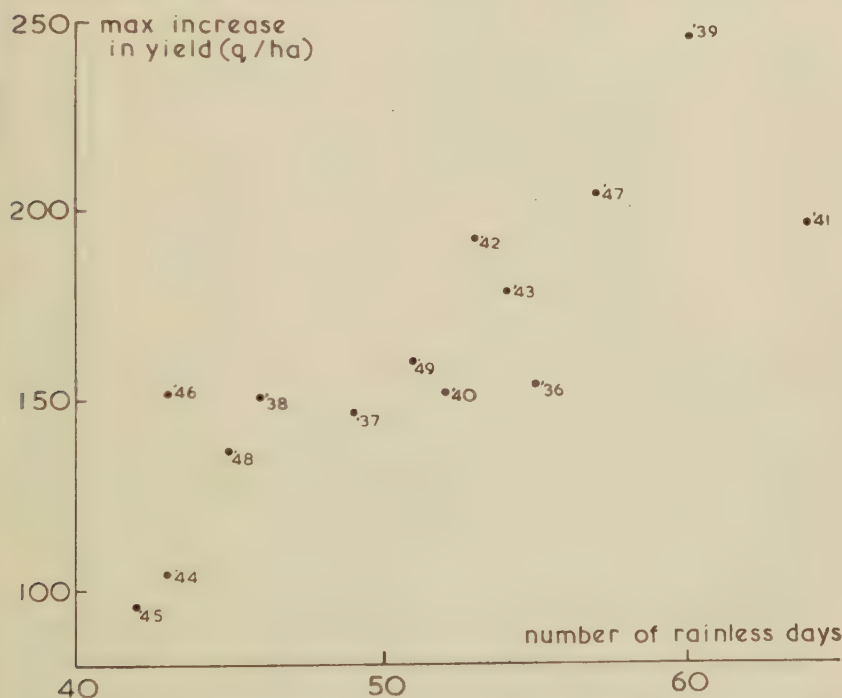


Fig. 3. Relation between the number of rainless days (May-July) and the maximum increases in yields of potato tubers obtained after applications of potash.

(without the results for the year 1945 it is 0.80) and is highly significant. The correlation coefficient for percentage increases in yield is calculated to be -0.74 (without the results for the year

1945 it is -0.80). Evidently the effect of potash dressings is greatest in dry years, which corresponds to a low availability of soil potash.

Rainfall (in mm) shows less correlation with crop response. For the same period the correlation between this factor and the increase in yield is rather weak ($r = -0.35$). This might be due to the fact that the values for rainfall, having been measured at a distance of 6 km from the experimental field, may not represent the actual

TABLE I

Correlation between number of rainless days in May-July and crop responses to potash applications			
Grop	Response	r	p
Potato	Diff. of yields (max.—min.)	0.84	<0.001
	Same without 1945.	0.81	<0.001
	Relative yields without K.	-0.74	0.001
	Same without 1945.	-0.80	0.001
	Depression under-water-weights (max.—min.)	-0.71	<0.01
	Same without 1945.	-0.65	0.02
	Max. $K_2O\%$ tubers with K	-0.47	0.09
	Same without 1941.	-0.32	0.30
	Same without 1941 and 1947.	-0.75	<0.01
	$K_2O\%$ tubers without K	-0.18	0.53
	Same without 1941.	-0.52	0.06
	Same without 1941 and 1947.	-0.61	0.03
Spring wheat	Diff. of yields (grain) (480—0)	0.69	0.01
	Relative yields (480 in % of O).	0.67	0.01
	Relative yields without K (straw)	-0.16	0.61
Canary grass	Diff. of K_2O -contents (max.—min.) (straw) .	-0.56	0.07
Beans	Relative yields without K (seed + straw) . .	-0.11	0.74

rainfall on this field. A higher correlation ($r = -0.52$) is indeed found if the mean of the rainfalls for 5 meteorological stations (at distances of 6–20 km) is taken.

With the exception of 1936 and 1945 the relation between level of potash dressing and under-water-weight can be characterized by a curve showing an optimum (the average relation is shown in Fig. 1). From the shape of the curves obtained in 1936 and 1945 it can be concluded that in these years the optimum value must have occurred under conditions where little or no potash was applied. The difference between the optimum values and the minimum values obtained with the highest level of application can be used as an index of potash availability (van der Paauw ⁷). A clear correlation is found between this difference in the under-

water-weight and the number of rainless days (Table I, Fig. 4). The difference is greatest in wet years. This suggests an abundant potash supply in those years on the plots heavily dressed with potash.

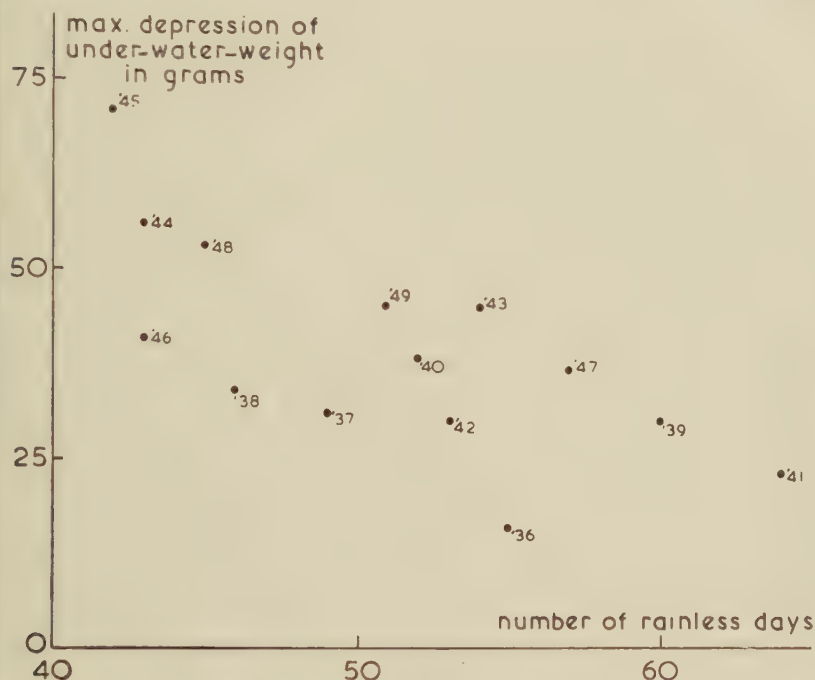


Fig. 4. Relation between the number of rainless days (May-July) and the maximum depression of the under-water-weights of potato tubers caused by high levels of potash application.

It may be noted that the optimum value of the under-water-weight itself is not correlated with the number of rainless days. It seems probable that the optimum values depend not only on potash nutrition but on all the factors influencing the starch content in the different years. In addition the optimum level of potash application varies from year to year.

Relatively low decreases of the under-water-weights were found in the years 1936-1938. This may be fortuitous but it may also be the result of a continuing, somewhat lower potash status during the first few years of the experiment in the case of the plots receiving large applications. Parallel deviations were, however, not

found in the case of maximum increase in yield of tubers (Fig. 3) or in the case of K_2O content of tubers (Fig. 5). Therefore, it is probable that the results obtained during these years are comparable with those of other years.

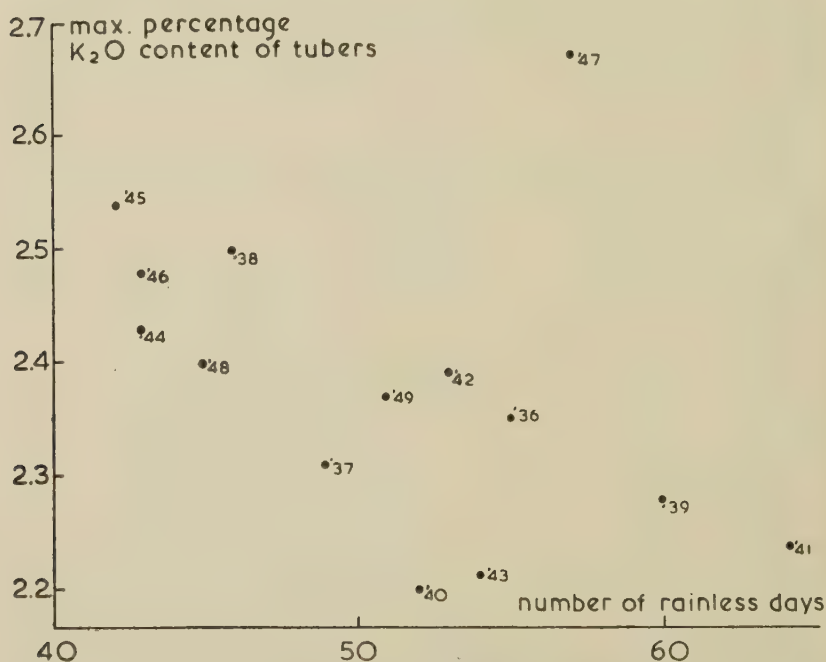


Fig. 5. Relation between the number of rainless days and the K_2O content of potato tubers after high levels of potash application.

A similar trend in the chemical composition of the crop would, however, have been the strongest argument in favour of the assumption of an increased availability of potash in wet years. The correlation coefficient for the relation between K_2O contents of tubers from plots receiving the largest application of potash and the number of dry days is, however, not fully significant (Table I, Fig. 5). It should be mentioned that the result for the year 1941 is rather unreliable. The curve of values for the K_2O contents of tubers plotted against the level of K_2O application (Fig. 6) shows the 1941 values to be very irregular, especially in the case of the K_2O content for tubers grown in the absence of added potash. It seems probable that sampling errors have been made. If the values for 1941 be omitted

the correlation coefficient drops from -0.47 to -0.32 . The results for 1947 also deviate considerably from the general trend. This year was extremely hot and also dry at the end of the growing season. If the result for 1947 is omitted, then the correlation coefficient rises to -0.75 .

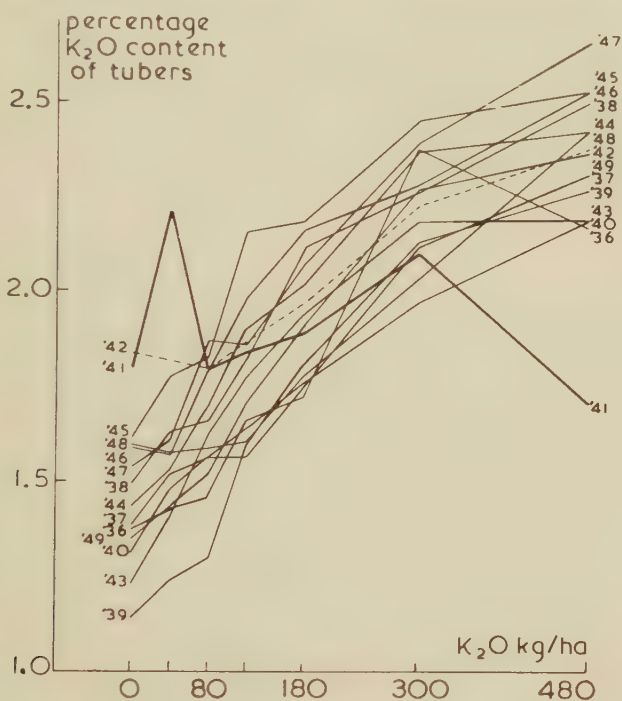


Fig. 6. Relation between the application of increasing amounts of potash and the K₂O content of the potato tubers for all the years of the experiment.

In the case of K₂O contents for tubers grown in the absence of added potash a result obtained in 1935 is also available. The correlation is, however, weak. If, however, the doubtful value for 1941 is omitted, the correlation is greater (Table I).

However, the results from the above data are not sufficiently significant for there to be a definite indication of an increased intake of potash under rainy weather conditions.

2. Spring wheat

The response of this crop to potash applications is much less

than in the case of potatoes. In addition the effect of potash on yield is characterized by an optimum in most cases (Fig. 1). In those years when the amount of available potash is low a curve indicating gradual increase in yield with increase in potash application is obtained, in the years when the amount of available potash is high the positive effect of application of potash is slight and the depressing effect on the yield is dominant. It is not easy to

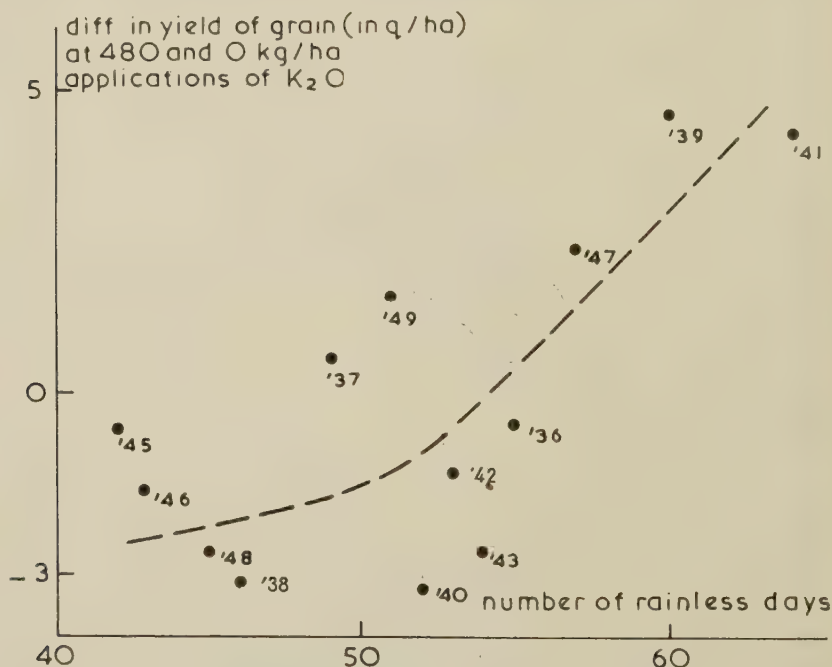


Fig. 7. Relation between the number of rainless days (May-July) and the differences in the yields of wheat obtained in the presence (480 kg/ha) and absence of applications of potash.

characterize such effects by a single index. The yield obtained with the highest dressing is affected positively and negatively. The difference between the yield obtained with the highest potash application and the yield obtained in the absence of a potash dressing appeared to be the most suitable index.

The relation between the number of rainless days and the difference between the yields obtained with and without a potash dressing is shown in Fig. 7. Positive responses to applications of

potash have been found in dry years, negative responses especially in wet years. This result points to a higher availability of potash in rainy years and agrees with the result obtained for potatoes.

Probably the relation cannot be represented correctly by a straight line. It seems that the part of the curve nearest the origin has a much less steep slope. This is in agreement with the mean response of this crop to increasing amounts of added potash (Fig. 1). Very high applications of potash did not depress the yield appreciably more than did moderate dressings.

The response of straw to applications of potash does not appear to be noticeably increased in dry years (Table I).

3. Canary grass

Only weak correlations between weather conditions and influence of potash supply on yield were found in the case of this crop. The clearest correlation has been found for the relation between the number of rainless days and the increase in the K_2O content of the straw. This relation is mainly detectable from the variations in the maximum K_2O content of the straw obtained at the highest levels of potash application. The increase in the K_2O content was greatest in wet years.

Although this finding is not fully significant (Table I) it agrees with the results obtained for potatoes and wheat.

4. Beans

No correlations were found in the case of this crop (Table I).

It is curious that the behaviour of this crop, which is very sensitive to potash deficiency, is so different when compared with that of the other crops.

Period of highest sensitivity

In order to determine more accurately the period during which the crop is most sensitive to the meteorological factors affecting the response to potash, correlation coefficients for the relation between the weather index over shorter periods and the response of the crop have been calculated. The increases in yield of potatoes obtained after applications of potash have been taken (Table II) as the measure of crop response.

TABLE II

Correlation between number of rainless days during different periods of the growing season and increases in yields of tubers		
Period	r	p
1-30 April	-0.20	0.50
16 April-15 May	0.35	0.23
1-31 May	0.64	0.01
16 May-15 June	0.77	<0.01
1-30 June	0.68	<0.01
16 June-15 July	0.12	0.69
1-31 July	-0.10	0.74
16 July-15 August . . .	-0.32	0.27
1 May-30 June	0.78	0.001
1 June-31 July	0.59	0.02
1 May-31 July	0.84	<0.001
1 May-15 August	0.71	<0.01

Obviously the correlation coefficient increases until the period 16 May-15 June and then regularly decreases again. This regularity may indicate that the potato crop is especially affected during the period of emergence and early development of the crop.

The highest correlations for the differences in yield of wheat have been obtained for the period 16 May-15 June ($r = 0.41$, $p = 0.17$). No clear correlations were found for May and July. For the period 1 May-31 July the correlation is 0.69 ($p = 0.01$) (Table I).

In the case of canary grass the correlation between the maximum increase in K_2O content of the straw and the number of rainless days is also highest for the period 16 May-15 June ($r = -0.50$, $p = 0.12$). For the period 1 May-31 July a value of -0.56 has been obtained (Table I).

In the case of beans no significant correlations were found for the shorter periods.

The nature of the climatological factor responsible for the crop responses

The correlations found between the weather index and crop response to potash supply do not reveal the real causal effect of climatological factors. The number of rainless days may give an indication of the amount of precipitation and the moisture content of the soil but it may equally well be an indication of hours of sunshine, light intensity, temperature, or other factors. The small

number of experimental years does not allow a further analysis to be made.

It might be that differences in moisture content of the soil result in differences in the amounts of available potash (Schuffelen and Middelburg¹², Schuffelen¹³). The increases in K_2O content of crops might be considered to support this hypothesis. It seems feasible that the apparently increased availability of potash is due to an increase in the K-concentration in the soil solution rather than to an increased capacity of the plants to absorb potash. It is generally accepted that good weather conditions (high light intensity) are more favourable for potash absorption by the plants. It appears, however, that a large number of dry days coincides with *low* potash contents in potatoes and canary grass.

Differences in potash absorption may also be due, however, to temperature levels or variations in temperature, as has been shown by Dijkshoorn and 't Hart¹.

SUMMARY

Significant correlations have been found between the response of potatoes, spring wheat, and to some extent canary grass to applications of potash and the number of rainless days during the growing period.

The influence of applications of potash on the tuber yield of potatoes was higher, on the depression of the under-water-weight of the tubers was less, and on the K_2O content of the tubers was lower, in dry years thereby indicating a decreased availability of soil potash in these years.

The positive effect of applications of potash on the grain yield of wheat was highest in dry years. Ample applications of potash were found to depress yields in wet years which is also an indication of higher availability of potash in wet years.

In the case of canary grass greater increases in the K_2O content of the straw after applications of potash were found in wet years.

No significant correlations were found in the case of bean crops.

The influence of weather conditions on the response to potash is probably greatest during emergence and the early phases of growth. In later periods the influence is slight.

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INVESTIGATIONS ON THE DETERMINATION OF
THE AVAILABLE MANGANESE CONTENT OF SOILS

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Various methods have been used for the determination of the manganese content in the soil which is available to plants. Attempts have been made to determine the manganese partly as an exchangeable fraction by extraction with a neutral electrolyte and partly as a reducible fraction by treatment of the soil with a reducing agent.

When a soil is extracted with a salt solution, the exchangeable fraction of the manganese content in the soil will probably also contain manganese which has been bound complexly and perhaps manganese released by reduction of higher manganese oxides as well. But, at any rate, it must be assumed that the so-called exchangeable fraction constitutes that part of the manganese content of the soil which is available to the plants at a given time, whereas a determination of the content of reducible manganese in the soil indicates that part which may be available to the plants over a given period.

In Denmark the method worked out by Steenbjerg¹³ for the determination of the amount of exchangeable manganese in the soil has been used and the results of this method have proved to be a valuable aid for the estimation of the supply of manganese by the soils in practical farming.

With Steenbjerg's method the exchangeable manganese is extracted with *M* magnesium nitrate, 100 g air-dried soil being placed in a Büchner funnel with a diameter of 9 cm. After a slight compression of the soil, magnesium nitrate is added continually to the soil until a total of 100 ml of the leachates has been collected, 25 + 25 + 50 ml being collected successively and the manganese is determined colorimetrically after oxidation to permanganate.

In order to obtain the volumes mentioned, very varying volumes of magnesium nitrate are used, depending on the ability of the soil analyzed to retain the solution used. Thus there is no constant ratio between soil and extracting agent, just as the time of extraction may vary from about 5 minutes with a light sandy soil to several hours with a very heavy clay soil. Furthermore, it is not possible to extract soils rich in humus in a 9-cm Büchner funnel without moistening them beforehand, as a result of which they swell so much that there is not room for 100 g soil in the Büchner funnel used. Therefore only 50 g of these soils is extracted.

The varying time of extraction and the want of a constant ratio between soil and extracting agent must be considered fundamental defects of the leaching method. The varying time of extraction is probably due to the physical qualities of the soils, which are not necessarily correlated to the ability of the soils to supply the plants with manganese.

In view of the above mentioned, and as the leaching method is rather time-consuming, it seemed desirable to change the extraction technique to extraction of the soil by mechanical shaking as was done by Heintze⁵, who used calcium nitrate as an extracting agent, 10 g soil being shaken with 250 ml calcium nitrate. At this ratio between soil and extracting agent Heintze in a comparison with Steenbjerg's method used 0.5 molar solutions of magnesium nitrate and calcium nitrate and found that an average of about 70 per cent more manganese was extracted from 21 soils by the shaking method and calcium nitrate than by leaching with magnesium nitrate.

METHODS

All *pH* measurements were made with a glass electrode.

The *calcium carbonate* and *carbon* contents of the soils were determined respectively by the use of the Scheibler and the Ter Meulen apparatus.

The *total manganese* content of the soil was determined by boiling 20 g of air-dried soil with 200 ml of 20 per cent hydrochloric acid for one hour, using a reflux condenser. The mixture was allowed to cool. After addition of nitric acid the extract was evaporated on a water bath and the content of manganese was determined colorimetrically in the same way as in analyses of extractable manganese.

Extractable manganese. Manganese in the filtrates was oxidized to permanganate by potassium persulphate in the presence of phosphoric acid and silver ions and determined colorimetrically.

EXPERIMENTAL RESULTS

a. *The dependence of extractable manganese on the ratio between the volume of the extracting agent, and the amount of soil used.*

The soils were extracted with M magnesium nitrate and M calcium nitrate, respectively. The volume of the extracting agent was kept constant at 200 ml. In this volume 5, 10, 20, 40 and 50 g soil respectively were shaken for one hour in a shaking apparatus making about 50 revolutions per minute. In this way the following ratio between the volume of the extracting agent and the amount of soil used was 40, 20, 10, 5, and 4.

The soils used for this examination are described in Table I, and the examination was made on air-dried samples which had been stored at room temperature from about six months to one year.

TABLE I

Description of the soils used						
Soil No.	Locality	Soil type	pH	CaCO ₃ %	C %	Total Mn, ppm
1	Virungaard.	Loam	6.0	0	1.5	400
2	Faarevejle	Muck	6.2	0	8.4	280
3	J. Lyngsgaard, Ringsted	Low moor peat	7.1	0	18.5	225
4	P. Hansen, „	Sandy soil	8.1	2.8	4.5	160
5	Hans Nielsen, „	Black fen	8.2	8.1	11.8	140
6	Vilbjerg	Sandy soil	5.4	0	4.4	65
7	Bonderød.	Loam	7.0	0	3.2	260
8	Store Heddinge	Heavy loam	7.1	0.1	1.4	420
9	Ørsløv	Sandy soil	6.9	0.1	5.4	125
10	Valsøllilegaard	High moor peat	6.0	0	30.2	200
11	Slettebjerggaard. . . .	Sandy soil	6.2	0	1.6	480
12	Gejlå	Sandy soil	6.5	0	2.2	260
13	Kirke Eskildstrup . . .	Bog	6.7	0.1	24.6	330
14	Bække	Sandy soil	6.1	0	5.6	165
15	Gravlev	Muck	5.8	0.1	25.0	430
16	Mørkøv	Peat soil	6.2	0	13.9	350
17	Lundby	Peat soil	8.2	25.9	12.8	240
18	Hølkerup, Braade . . .	Loam	7.9	1.3	2.0	380
19	Beder	Loam	6.8	0	3.3	215
20	Aalholm, Nysted . . .	Loam	7.4	0.1	1.0	390
21	St. Jyndevad.	Sandy soil	7.7	0.4	1.9	270

The results of the extraction tests are given in Table II and are indicated directly in ppm extractable manganese. In Table III, these values are converted to percentages of extracted manganese

in the total content of manganese in the soil for the various ratios between the volume of the extracting agent and the amount of soil used.

TABLE II

Ppm manganese extracted after shaking varying amounts of soil with 200 ml molar solutions of magnesium nitrate and calcium nitrate for one hour										
Soil No.	Ratio of the volume of the extracting agent to the weight of the soil									
	40		20		10		5		4	
	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca
1	12.8	24.8	12.8	18.4	12.5	15.0	11.0	13.0	10.4	12.8
2	19.2	32.0	18.4	24.0	16.0	20.0	13.5	16.0	12.0	—
3	17.6	36.8	16.8	24.0	13.0	19.0	9.5	13.0	8.0	12.0
4	4.0	16.8	4.0	9.6	3.0	5.2	2.4	3.8	2.8	3.7
5	4.0	17.6	3.2	8.8	2.7	4.8	2.2	3.0	1.7	2.4
6	7.2	19.2	6.4	13.6	6.5	9.2	6.5	6.5	5.0	6.8
7	6.4	12.8	4.8	8.8	3.2	5.6	2.8	3.8	2.9	3.3
8	11.2	19.2	10.4	13.6	8.8	11.2	8.0	7.6	7.4	7.7
9	3.2	11.2	2.4	7.2	1.8	4.8	1.4	2.8	1.7	2.7
10	16.0	16.0	11.2	13.6	9.6	13.6	8.8	9.2	7.6	8.3
11	12.8	24.0	11.2	16.0	11.2	13.6	10.4	12.8	10.9	11.5
12	4.8	12.8	3.6	8.0	2.8	5.2	2.6	3.6	2.7	3.5
13	25.6	48.0	18.4	36.0	17.6	24.0	12.0	17.0	12.0	16.0
14	12.8	40.0	12.0	28.0	11.2	19.0	10.4	16.0	10.4	14.4
15	72.0	104.0	68.0	88.0	52.0	64.0	50.0	50.0	40.0	52.0
16	19.2	56.0	18.4	36.0	13.6	26.0	11.2	18.0	8.3	18.4
17	6.4	28.8	4.4	12.8	2.4	5.2	1.3	1.4	1.1	1.9
18	14.0	—	8.0	—	7.0	—	4.5	—	4.4	—
19	12.0	—	8.0	—	8.0	—	6.5	—	6.4	—
20	22.0	—	15.0	—	16.0	—	12.5	—	11.2	—

Tables II and III show that considerably larger amounts of manganese were released for both magnesium nitrate and calcium nitrate the wider the ratio between the volume of the extracting agent and the amount of soil used. Apart from soil No. 10 (high-moor peat) from about $1\frac{1}{2}$ to about 4 times as much manganese was extracted with calcium nitrate as with magnesium nitrate at the ratio 40, but the difference between the abilities of the two salts to extract manganese from the soils tested was minimized as the ratio between the volume of the extracting agent and the amount of soil used was reduced to 4. However, even with this ratio, most manganese was extracted with calcium nitrate.

TABLE III

Contents of extracted manganese in soil extracts as percentages of the total content of manganese in the soil after shaking varying amounts of soil with 200 ml molar solutions of magnesium nitrate and calcium nitrate for one hour											
Soil No.	Ratio of the volume of the extracting agent to the weight of the soil										
	40		20		10		5		4		
	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	
1	3.2	6.2	3.2	4.6	3.1	3.8	2.8	3.3	2.6	3.2	
2	6.9	11.4	6.8	8.6	5.7	7.1	4.8	5.7	4.3	—	
3	7.8	16.4	7.5	10.7	5.8	8.4	4.2	6.2	3.6	5.3	
4	2.5	10.5	2.5	6.0	1.9	3.3	1.5	2.4	1.8	2.3	
5	2.9	12.6	2.3	6.3	1.9	3.4	1.6	2.1	1.2	1.7	
6	11.1	29.5	9.8	20.9	10.0	14.2	10.0	10.0	8.3	10.5	
7	2.5	4.9	1.8	3.4	1.2	2.2	1.1	1.5	1.1	1.3	
8	2.7	4.6	2.5	3.2	2.1	2.7	1.9	1.8	1.8	1.8	
9	2.6	9.0	1.9	5.8	1.4	3.8	1.1	2.2	1.4	2.2	
10	8.0	8.0	5.6	6.8	4.8	6.8	4.4	4.6	3.8	4.2	
11	2.7	5.0	2.3	3.3	2.3	2.8	2.2	2.7	2.3	2.4	
12	1.8	4.9	1.4	3.1	1.1	2.0	1.0	1.4	1.0	1.3	
13	7.8	14.5	5.6	10.9	5.3	7.3	3.6	5.2	3.6	4.8	
14	7.8	24.2	7.3	17.0	6.8	11.5	6.3	9.7	6.3	8.7	
15	16.7	24.2	15.8	20.5	12.1	14.9	11.6	11.6	9.3	12.1	
16	5.5	16.0	5.3	10.3	3.9	7.4	3.2	5.1	2.4	5.3	
17	2.7	12.0	1.8	5.3	1.0	2.2	0.5	0.6	0.5	0.5	
18	3.7	—	2.1	—	1.8	—	1.2	—	1.2	—	
19	5.6	—	3.7	—	3.7	—	3.0	—	3.0	—	
20	5.6	—	3.8	—	4.1	—	3.2	—	2.9	—	

b. Influence of the pH value of magnesium nitrate on the amounts of manganese exacted from the soils

The pH value in a molar solution of magnesium nitrate of the manganese-free reagent (Merck) used in Denmark for the determination of the amount of available manganese in the soil, may vary from about 3.5 to about 6. It was therefore decided to investigate whether the pH value of the solution of magnesium nitrate had any influence on the amount of manganese which was dissolved when 20 g soil was shaken for one hour with 200 ml molar solutions of magnesium nitrate with pH values ranging between 4.5 and 8.1.

Solutions of magnesium nitrate with different pH values were made by adding sodium hydroxide to a solution of magnesium nitrate with a low pH value. The pH of the soil suspension was measured immediately after the shaking. The results appear in Table IV.

TABLE IV

Extractable manganese in 20 g soil shaken for one hour with 200 ml molar solutions of magnesium nitrate with different pH values										
pH in Mg(NO ₃) ₂	Soil No. 10 pH 6.0		Soil No. 11 pH 6.2		Soil No. 12 pH 6.5		Soil No. 9 pH 6.9		Soil No. 8 pH 7.1	
	pH in soil suspension	ppm Mn	pH in soil suspension	ppm Mn	pH in soil suspension	ppm Mn	pH in soil suspension	ppm Mn	pH in soil suspension	ppm Mn
4.46	4.71	19.2	4.80	6.4	4.78	2.1	5.34	3.6	5.98	14.4
5.35	4.70	19.2	4.85	6.7	4.82	2.1	5.29	3.4	6.05	14.4
6.48	4.72	19.2	4.94	6.7	4.88	2.1	5.30	3.4	6.13	14.4
7.38	4.76	19.2	4.93	6.7	4.93	2.1	5.46	3.4	6.12	14.4
8.10	4.75	19.2	5.10	6.7	5.05	2.1	5.43	3.5	6.26	14.4

It is possible at a 10 to 1 ratio between the volume of the extracting agent and the weight of the soil to use molar solutions of magnesium nitrate with different pH values without this changing the amount of manganese extracted.

c. Influence of the time of shaking on the amount of manganese extracted

20 g samples of 8 different soils were shaken with 200 ml *M* magnesium nitrate for $\frac{1}{2}$, 1, 2, 4, 6, and 24 hours, respectively. The results are shown in Fig. 1.

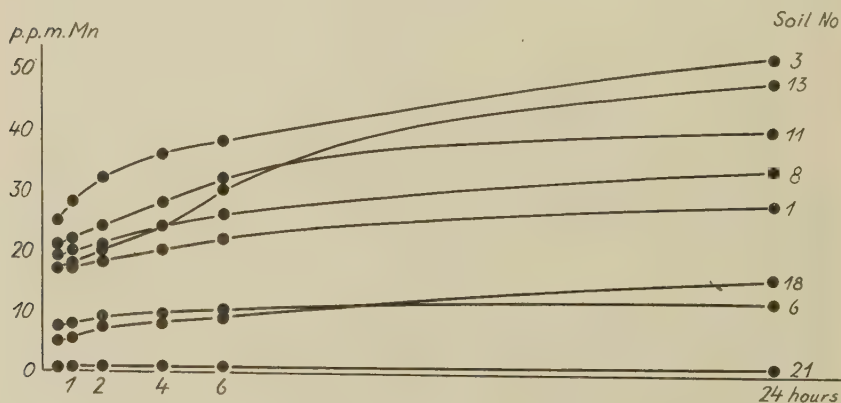


Fig. 1. Influence of time of shaking on extractable manganese in soil extracts.

As appears from the figure, equilibrium was not obtained after shaking for 24 hours. If the amounts of manganese found at various times of shaking are converted to relative values so that the amount

of manganese extracted after shaking for $\frac{1}{2}$ hour is put at 100, the relative values shown in Table V are obtained.

TABEL V

Influence of the shaking time on the relative contents of manganese in soil extracts							
Soil No.	Hours						
	$\frac{1}{2}$	1	2	4	6	24	
3	100	112	128	144	152	208	
13	100	106	118	141	176	282	
11	100	105	114	133	152	190	
8	100	105	110	126	137	179	
1	100	100	106	118	129	164	
18	100	108	144	154	173	308	
6	100	105	121	126	137	157	
22	100	113	125	125	150	150	

It is seen that unequal amounts of manganese are released from the various soils by an increase of the time of shaking.

d. *Manganese content in the soil extracts as compared with manganese supply of the crops*

A number of field experiments were made by the Danish associations of farmers and small-holders in 1955 (Dam Kofoed and Olesen ⁷), in Jutland, Zealand, Lolland-Falster, and Møen in order to illustrate the response of manganese sulphate to different crops. From 30 of these experimental fields with spring cereals and from 20 with root crops soil samples were taken in July for the determination of the content of extractable manganese in the soil. This material included 23 loamy soils, 17 sandy soils with less than 3 per cent C and 10 sandy soils with more than 3 per cent C. Within this collection of soil samples the pH of the soils ranged from 5.1 to 8.3, the contents of carbon from 0.94 to 24.6 per cent, and the percentage contents of calcium carbonate from 0 to 25.9.

Simultaneously with the sampling of the soils the crops were examined for visual symptoms of deficiency in manganese. These symptoms and (or) the yield figures were compared with the amounts of manganese extracted from the soils.

The extractable manganese was determined immediately after sampling by shaking 20 g air-dried soil with 200 ml *M* magnesium

nitrate for one hour. After filtration the contents of manganese were determined colorimetrically in a suitable aliquot. The results are indicated in ppm manganese.

When a limiting value of 4 was selected, 38 soil samples contained 4 ppm extractable manganese and less and were considered deficient in manganese. 12 soils contained more than 4 ppm manganese and were considered to be sufficiently supplied with this nutrient.

For the 38 soils containing 4 ppm manganese and less the crop obtained from 36 soils (95 per cent) must be considered deficient in manganese since responses to manganese sulphate added were observed or symptoms of manganese deficiency occurred in the month of July. On the two remaining soils with a content of 2.0 and 2.8 ppm manganese no symptoms of manganese deficiency were observed in the crops. The crop of one soil was not weighed at harvest and for the other soil no increase in yield was found for manganese sulphate added.

On the 12 soils which contained more than 4.0 ppm manganese, no symptoms of manganese deficiency were observed from 10 soils (83 per cent); nor was any increase in yield for manganese sulphate added found in 7 out of the 10 soils in which the crops were weighed after harvest. On two soils with manganese contents of 4.4 (and 4.8 ppm the crop showed a positive response to addition of manganese.

For the collection of soil samples mentioned in this section a comparison was made between the values for extractable manganese found by the "shaking method" used here and the amounts of manganese dissolved when the content of manganese is determined by leaching 100 g soil. These investigations have been described in detail elsewhere (Boken ³). Mention is only made of the average values found by the two methods, and their quantitative and qualitative connexion as described by the regression coefficient b and the correlation coefficient r , respectively, as shown in Table VI.

As appears from Table VI, average values of the same order of magnitude were found for all the three types of soil by use of the two methods of extraction, even though 5 times as much soil was used for the leaching method. Furthermore, it was not possible to point out any connexion between the contents of carbon in the 50 soil samples and the differences found between the results of the two methods of analysis.

TABLE VI

Extractable manganese in soil extracts after leaching and shaking of the soil with <i>M</i> magnesium nitrate					
Number of soils	Soil type	Ppm manganese average		<i>b</i>	<i>r</i>
		Leaching	Shaking		
23	Loam	2.0	2.6	1.02 ± 0.05	0.91 ± 0.07
17	Sandy soil, below 3% C	1.9	2.8	1.13 ± 0.10	0.95 ± 0.03
10	Sandy soil, above 3% C	3.9	4.1	1.02 ± 0.11	0.95 ± 0.03

e. Dependence of the extracted manganese on the content of carbon in the soil

For the soils mentioned in Tables II and III the influence was investigated of the contents of carbon in the soil on the decrease in the amount of manganese dissolved in magnesium nitrate when the ratio between the volume of the extracting agent and the amount of soil used was reduced from 40 to 4. The decrease was calculated as a percentage of the amount of manganese in ppm found at the ratio 40.

The percentage decrease for each soil was compared with the percentage content of carbon in the soil in question (Fig. 2) where

% Decrease in extractable manganese

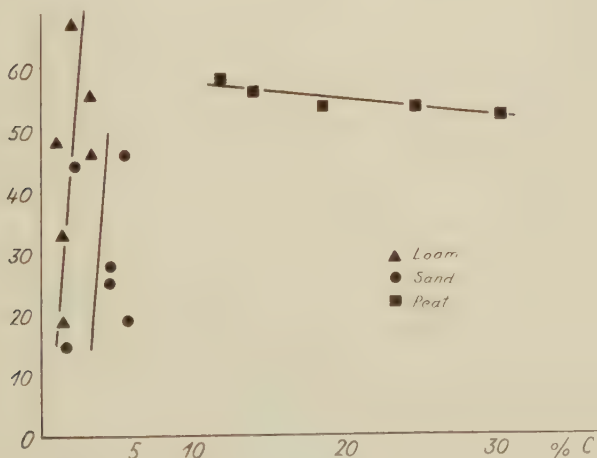


Fig. 2. Relationship between carbon content in the soil and decreases in extractable manganese found when the ratio between the volume of the magnesium nitrate solution and the amount of soil used was reduced from 40 to 4.

the three curves indicate loamy, sandy, and humus soils. The comparison does not include three soils deviating from the above-mentioned types of soil, viz. Nos. 2, 15, and 5, as Nos. 2 and 15 are muck and No. 5 bog soil with a large content of lime.

As appears from Fig 2, the curves which describe the above-mentioned relationship have different slopes for loamy and sandy soils on the one hand and humus soils with more than 11 per cent C on the other. Similar results were obtained when the soils were extracted with calcium nitrate. This suggests that the quality of the humus substances is also of importance for the extractable amount of manganese.

It has previously been shown (Boken ²) that if air-dried soil samples are stored at room temperature, the content of exchangeable manganese increases. Of the soils mentioned on p. 275 samples of 21 loamy soils and 18 sandy soils, all with 4 per cent C and less, were investigated to see whether it was possible to demonstrate any connexion between the increase mentioned and the percentage contents of carbon in the soils.

The contents of extractable manganese in the soils were determined in an air-dried soil sample 24–48 hours after the sampling in July 1955, 20 g soil being shaken for one hour with 200 ml *M* magnesium nitrate. In July 1956 this analysis was repeated in the soil samples after they had been stored in closed tins for a year at room temperature (20–24° C). It appeared that the content of extractable manganese had increased in all soil samples. The increases found, as calculated as a percentage of the content of extracted manganese in the soils in July 1955 was correlated to the percentage contents of carbon in the soils as shown in Table VII.

TABLE VII

Connexion between the percentage content of carbon and the increase in the content of extracted manganese in 39 mineral soils after storing for one year at room temperature		
Percentage of C	Increase in extracted manganese, %	Number of soil samples
0—1.0	589	2
1.1—2.0	319	19
2.1—3.0	176	13
3.1—4.0	181	5

As appears from Table VII, there is a connexion between the percentage contents of carbon in the mineral soils analyzed and the increase in the contents of extracted manganese in these soils following storage at room temperature for a year, the increase in extracted manganese being reduced with soil samples of higher carbon content. If the comparison shown in Table VII is made for sandy and loamy soils separately the same trend can be demonstrated.

In the 39 soils mentioned above the absolute and the relative increase in extractable manganese after one years storage was compared to their pH values (Figs. 3 and 3a). No immediate relationship was found between these values.

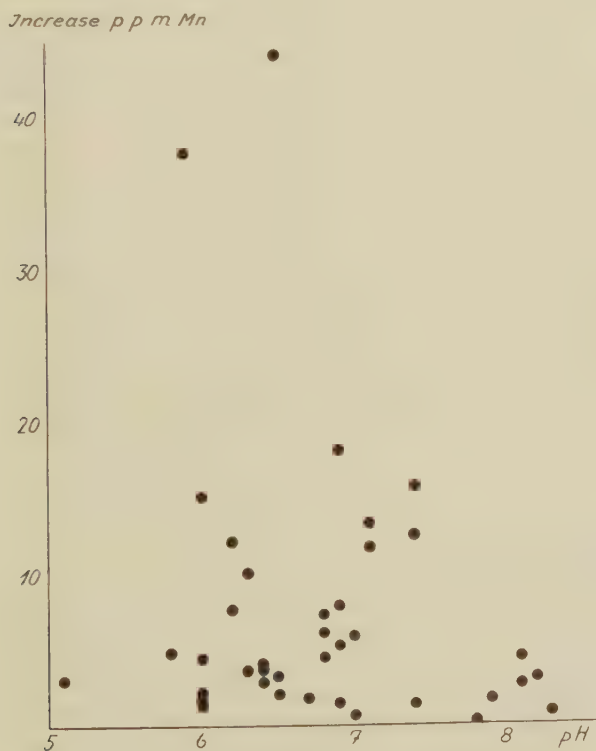


Fig. 3. Relationship between soil pH and increase in the absolute content of extractable manganese in 39 soil samples after one year's storage.

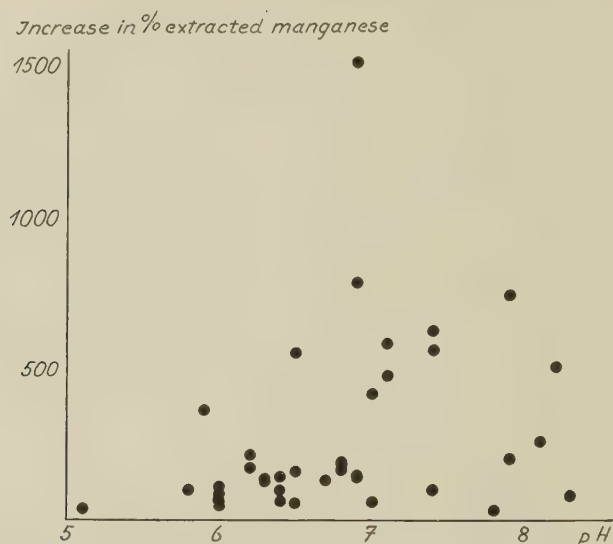


Fig. 3a. Relationship between soil pH and increase in the relative content of extractable manganese in 39 soil samples after one year's storage.

DISCUSSION AND CONCLUSIONS

Under the climatic conditions in Denmark, where spring cereals are mostly sown in late March on the light soils, the first symptoms of manganese deficiency in oats and barley growing on soils with insufficient supplies of manganese are observed when the temperature rises in May. This along with the fact that it is often observed that the symptoms of manganese deficiency disappear during the summer – perhaps partly as a consequence of further amounts of manganese being made available to the plants from more easily reducible manganese oxides – suggest that with these cereals a critical period exists regarding their supply of manganese six or seven weeks after sowing time. This is in agreement with the findings of Steenbjerg and Boken¹⁶ in 1939 that the manganese concentration in the dry matter of oats and barley growing on soil slightly deficient in manganese was greater in May than in June.

Furthermore, Nicholas and Fischer⁹ and Nicholas¹⁰ in field experiments with oats showed “that there was a significant relation ($P > 0.05$) between manganese content of the midstem leaves and final yield during early season (sampled 9/5 and 19/5,

1949), but that later there was no correlation (sampled 30/5, 9/6 and 20/6, 1949)." Finck⁴ also showed that in water-culture experiments with oats an adequate supply with manganese in a period which has its maximum 50-60 days after sowing, determines the yield of this plant.

For peas Ovinge¹¹ showed that fertilization of the soil with 100 kg manganese sulphate per ha immediately before flowering controlled Marsh Spot much better than fertilization with the same amount of manganese earlier when the plants were about 10 cm high. Lewis⁸ found that when manganese was added by spraying, the most effective control of Marsh Spot was obtained by spraying when the peas were in bloom. Heintze⁶ in pot experiments on soil deficient in manganese grown with peas in which a solution of manganese sulphate was added by injection into the plant at various times during the growing season found "that the control of Marsh Spot in peas required an adequate supply of manganese throughout the whole period of seed formation".

For tomatoes Ahmed and Twyman¹ in water-culture experiments found that "for the period from germination to the setting of fruit on the first truss manganese was necessary only during the fifth or sixth week after sowing. The manganese absorbed during this short period was sufficient for normal growth for a further four or five weeks."

Thus it has been shown, for a number of different plants, that an adequate supply of manganese at certain times during the development of these plants determines the yield obtained. Hence it must be assumed that methods capable of reflecting the amount of soil manganese readily available to the plants is of the greatest interest to practical farming.

Quite a good agreement (Steenbjerg¹⁴, Schachtschabel¹²) has been found between amounts of manganese determined after extraction of the soil with a solution of magnesium nitrate and the symptoms of manganese deficiency of the plants. This agreement would perhaps be better if the soil samples for determination of manganese were taken at the time in the growing season of the plant in question when insufficient supply of manganese is of the greatest importance for the yield of the plant.

As a result of the investigations reported above it is proposed to change the extraction technique hitherto used in this country

(the leaching method) to a shaking method, so that 20 g soil is shaken with 200 ml *M* magnesium nitrate for one hour. In this way a constant ratio is obtained between the volume of the extracting agent and the amount of soil used. The ratio 10 : 1 is convenient to adopt. It is true that more manganese is extracted with a solution of calcium nitrate than with a solution of magnesium nitrate of the same strength even though the difference between the abilities of the two salts to release manganese is minimized when the ratio between the volume of the extracting agent and the amount of soil used is reduced. But when using empirical methods of analysis for the determination of the contents of nutrients in the soils it is advantageous to always use the same extracting agent in the same strength so that comparisons may be continued between results of analysis and the growth of the crop.

A volume of 200 ml is chosen for practical purposes. When 20 g soil is shaken with 200 ml *M* magnesium nitrate solution, the buffer capacity of the soil suspension is so great that differences in the pH values from 4.5 to 8.1 of the solutions of magnesium nitrate do not influence the amount of manganese released by shaking for one hour. Furthermore, it is not difficult to take a representative average sample of any soil sample when 20 g soil are used.

As it is desirable to determine the amount of manganese that is readily available to the plants (an amount which is supposed to be correlated to the amount of manganese extracted) it is necessary that the shaking time be as short as possible. A shaking time of one hour was chosen, although as has been shown it might be more expedient to use half an hour. The contact of the soil with the extracting agent does not cease at the end of the shaking time, but is continued during the filtration, and as the soils are not filtered at quite the same rate, this difference between treatments of the various soils constitutes a smaller part of one hour than of half an hour.

At an appraisal made by Schachtschabel¹² in which the amount of manganese dissolved in magnesium nitrate was used as an indicator of "healthy" and "sick" soils, the best agreement between the contents of manganese in the soils and the symptoms of manganese deficiency of oats was found when the limiting value between "sick" and "healthy" soils was put at 4 ppm manganese for a collection of podsolized sandy soils with less than 6 per

cent humus and pH $\sim$ 5.8 sampled in the month of June 1955 on the Lüneburg heath. If this limiting value is applied to the soils mentioned on p. 275, the samples were taken in the month July 1955, including different types of soil with more varying pH values and contents of carbon than the German sandy soils, it is found that there is a better agreement between the amounts of manganese extracted with magnesium nitrate and the symptoms of manganese deficiency in the plants and the responses of the plants to manganese sulphate. This might be supposed to be due to the fact that 40 per cent of the Danish material included comparisons in which the crop was a root crop, which probably has its optimum consumption of manganese at a later time than oats.

Thus it is questionable whether it is possible to fix *one* limiting value for soils deficient in manganese and soils not deficient in manganese as the magnitude of this limiting value must, amongst other things, be dependent on the species and variety of the crop (Steenbjerg and Boken¹⁵) and also upon whether there is enough manganese available to the plant at the time when manganese nutrition is most necessary to the plant in question. If the soil analyses are to be a guide in this respect, these factors must also be considered.

Zende¹⁷ using four Australian soils and two pH values of each soil found that the absolute increase in extractable (both ammonium acetate and $M/2$ calcium nitrate) manganese after air-drying the soils was greater the lower the pH, whereas the relative increase did not show any general trend. Following storage of four other air-dried soil samples Zende's results showed an absolute increase in the manganese extracted with $M/2$ calcium nitrate, after 13 years storage which was the greater the higher the pH in the soil at the end of the investigations. As appears from Figs. 3 and 3a, it was not possible in the case of 39 Danish mineral soils to find any immediate connexion between the pH of the soil samples and the absolute or relative increase in the amount of manganese extracted with magnesium nitrate after one year's storing of the air-dried soil samples.

For the 39 mineral soils a connexion was found between the percentage content of carbon in the soils and the increase in the amount of extracted manganese after a year's storing; the increase in extracted manganese being reduced with soil samples of higher carbon content (Table VII).

SUMMARY

The dependence of extracted manganese on the ratio between the volume of the extracting agent and the amount of soil used was investigated; 5, 10, 20, 40 and 50 g samples of soil, respectively, were shaken for one hour with 200 ml molar solutions of magnesium nitrate and calcium nitrate. For both magnesium nitrate and calcium nitrate considerably larger amounts of manganese were extracted the wider the ratio between the volume of the extracting agent and the amount of soil used. Most manganese was extracted with calcium nitrate; but the difference between the abilities of the two salts to extract manganese from the soil samples was reduced the narrower the ratio between the volume of the extracting agent and the amount of soil used.

When 20 g soil was shaken with 200 ml *M* magnesium nitrate solution for one hour, the buffer capacity of the soil suspension was so great that differences in the pH values of the solutions of magnesium nitrate from 4.5 to 8.1 did not change the amount of manganese extracted.

20 g soil was shaken with 200 ml *M* magnesium nitrate for $\frac{1}{2}$, 1, 2, 4, 6 and 24 hours, respectively. After shaking for 24 hours equilibrium was not obtained, and amounts of manganese of different size were obtained from various soils by an increase in the shaking time.

A comparison between the decrease in the amount of extractable manganese (which was found when the ratio between the volume of the extracting agent and the amount of soil used was reduced from 40 to 4) and the contents of carbon in loamy, sandy, and humus soils indicated (Fig. 2) that the quality of the humus substances is also of importance for the fixation of manganese in the soil.

For 39 air-dried soil samples taken from mineral soils it was not possible to find any immediate connexion between the pH of the samples and the absolute or relative increase in the amount of manganese extracted with magnesium nitrate after one year's storage. On the other hand, a connexion was found between the relative increase in the content of extractable manganese in the soils after being stored for one year and the percentage content of carbon in the soils, the increase in the content of manganese in the soils being reduced with samples of higher carbon content.

When the extractable manganese in the soils was determined by shaking 20 g air-dried soil for one hour with 200 ml *M* magnesium nitrate, it was found by a comparison between the results of this analysis and the symptoms of manganese deficiency in the plants and (or) the responses of the plants to manganese sulphate at a limiting value of 4 ppm manganese, that there was an agreement of 95 per cent in the case of "sick" soils and 83 per cent in the case of "healthy" soils. The soil samples were taken in the month of July in fields in which 60 per cent of the crops were spring cereals and 40 per cent root crops.

The quantitative and the qualitative connexions between the leaching method and the shaking method were found to be very close when *M* magnesium nitrate was used with both methods, the regression coefficients being 1.02 for loamy soils and sandy soils with more than 3 per cent C and 1.13 for

sandy soils with less than 3 per cent C. The correlation coefficient was 0.91 for loamy soils and 0.95 for sandy soils irrespective of their contents of carbon.

It is emphasized that if the chemical determinations of the contents of manganese in the soil are to be a guide to the ability of the soils to supply the crops with manganese, it is necessary at the interpretation of the results of analysis to consider the species and variety of crop concerned and to take soil samples for manganese analysis at the appropriate time during the development of the plant when an insufficient supply of manganese may well be of the greatest importance in determining the size of the crop yield.

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UPTAKE OF PHOSPHORUS FROM P^{32} -LABELLED SUPERPHOSPHATE BY FIELD CROPS

PART I. EFFECTS OF SIMULTANEOUS APPLICATION OF NON-RADIOACTIVE PHOSPHORUS FERTILIZERS

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INTRODUCTION

Phosphate fertilizers labelled with the isotope P^{32} , have been used extensively during the past ten years in field experiments in the United States and Canada but little work has been reported on the use of isotopes in similar experiments in Europe. The main conclusions from the American and Canadian experiments, some of which have been reviewed recently (Dean⁵, Mitchell¹²), have been that the percentage of phosphorus in crops which is derived from the labelled fertilizer depends on the phosphate status of the soil, on the crop grown and on the chemical form of the applied phosphate. Although total phosphorus uptake by crops is usually increased by the application of phosphate, considerably less is known about the effects of the phosphorus status of soils on the recovery of phosphorus from fertilizers. Using labelled fertilizers, the recovery of fertilizer phosphorus can be measured, even on soils which do not respond to phosphate fertilizers.

In the experiments described in this paper, the uptake of phosphorus from P^{32} -labelled superphosphate, placed near the seed for root crops or drilled in contact with the seed for barley, was measured at different stages of crop growth on contrasting sites at Rothamsted. The effects of the simultaneous application of broadcast non-radioactive phosphate fertilizers (superphosphate, dicalcium phosphate and Gafsa rock phosphate) on the uptake of

the placed superphosphate were also measured in each experiment. Five experiments with root crops (potatoes, fodder beet and swedes) and four with barley are described in this paper. One purpose of this study was to compare 'superphosphate equivalents' of the broadcast phosphate fertilizers calculated from yield response curves, from phosphorus uptake curves and from the decrease in the percentage of labelled superphosphate in the crop in the presence of broadcast non-radioactive fertilizers. The comparison of 'superphosphate equivalents' derived in this way from the results of two of the experiments described here, together with those from pot experiments, has been discussed briefly in a previous paper (Mattingly and Widdowson¹¹). Results obtained by a different method of calculating 'superphosphate equivalents' of the non-radioactive phosphate fertilizers are given below.

METHODS AND MATERIALS

The methods used to determine the total phosphorus content of the crops, and to estimate P^{32} , were essentially the same as those used for greenhouse experiments (Mattingly¹⁰). At harvest, the P^{32} -contents of the crops were very small and 5 g samples of dried and ground plant material were taken for analysis.

All experiments were carried out on two fields, Highfield and Sawyers, at Rothamsted, which have had a contrasting history of previous cropping. Highfield was ploughed up from pasture in 1951 and the soil, which was limed before ploughing, has a good structure. Sawyers is an old arable field which has received only occasional dressings of phosphate during the past 20 years. Analytical data on these soils are given in Table I. 'Available' phosphate was estimated by a rapid test in which 4 g of soil are shaken for one minute with 10 ml of 0.3N hydrochloric acid; phosphorus was determined in the filtrate by the molybdenum-blue method of Truog and Meyer¹³. This simple test has given reliable indications of 'available' phosphorus on soils from Rothamsted and the surrounding district.

TABLE I

Analytical data on Rothamsted soils from the experiments							
Site	Ref. no.	Year	pH (water)	% air-dry soil			
				CaCO ₃	Total P	Clay (<2 μ)	'Available phosphorus' (mg P per 100 g)
Highfield	A8867	1952	6.8	0.1	0.092	20.3	1.5
	A8953	1953	7.4	0.2	0.081	—	1.1
	A9170	1954	7.0	0.2	0.120	—	2.0
Sawyers	A8921	1953	5.3	nil	0.060	22.7	0.3
	A9169	1954	5.2	nil	0.064	—	0.4

The P^{32} -labelled superphosphate used in the experiments was prepared by the Radiochemical Centre, Amersham, Bucks, England, from bone ash and sulphuric acid containing radioactive phosphoric acid made by oxidising neutron-irradiated red phosphorus with nitric acid. The approximate specific activities at the dates of sowing in 1952, 1953 and 1954 were 0.26, 0.37, and 0.62 mC/g P_2O_5 respectively. The dicalcium phosphate and Gafsa rock phosphate were samples of commercial fertilizers. All phosphate fertilizers were applied on the basis of their total phosphorus content.

DESIGN AND SCOPE OF EXPERIMENTS

Table II gives full details of the crops tested in each year, the number of rows in a plot, the spacing of rows and the basal dressings of nitrogen and potassium which were applied as ammonium sulphate and potassium sulphate.

TABLE II

Details of crops, lay-out of experiments and basal nutrients applied in 1952, 1953 and 1954								
Crop	Variety	Year	No. of rows per plot	No. of active rows per plot	Spacing (in.)	Length of plot (ft.)	Basal nutrients, lb. per acre	
							N	K
Potatoes	Majestic	1952	5	1	20	10	90	100
Swedes	Best-of-all	1952	5	1	20	6	60	50
Fodder beet	Hunsballe	1952	5	1	20	6	90	100
	"	1953	10	2	20	18	90	100
	"	1954	7	2	20	18	90	100
Barley	Herta	1953	9	3	6	18	45	50
	"	1954	10	4	8	18	45	50

In each year superphosphate (10 lb. P per acre) was drilled 2 in. to the side of the seed and 2 in. below soil level on all plots in the experiments with root crops. Half this amount of superphosphate (5 lb. P per acre) was drilled in contact with the seed for barley. Radioactive superphosphate was applied to one or more rows in each plot, the remainder receiving an equivalent amount of non-radioactive superphosphate. In addition, broadcast non-radioactive phosphate fertilizers were applied at the following rates:

Broadcast (non-radioactive) phosphate fertilizers	Rate, lb. P per acre
None	0.0
Superphosphate	15.0
Superphosphate	30.0
Dicalcium phosphate	22.5
Gafsa rock phosphate	22.5

The experimental designs employed are described briefly below. In all years the crops were sown during the first or second week in May.

Three preliminary experiments on potatoes, swedes and fodder beet were carried out in microplots on Highfield in 1952. The centre row of each plot was drilled with P^{32} -labelled superphosphate, the remaining rows receiving non-radioactive superphosphate. The treatments testing broadcast phosphate fertilizers were arranged in a randomised block and there were three blocks in each experiment. The experiments on fodder beet in 1953 and 1954 were carried out in larger plots (Table II). Two rows per plot received P^{32} -labelled superphosphate and the remainder ordinary superphosphate. These experiments were arranged in each year in 5×5 Latin Squares. The barley experiments on Highfield and Sawyers were identical in design in the same year, but a slightly different arrangement of rows within plots was used in different years. In 1954 the spacing of rows was increased (Table II) to facilitate drilling and to reduce the incidence of powdery mildew which infected the barley sown in 1953. In both years the experiments were laid down in 5×5 Latin Squares, the five treatments being identical with those tested on fodder beet.

METHODS OF FERTILIZER APPLICATION, SAMPLING AND HARVESTING

Fertilizer application. In the potato experiment in 1952 superphosphate was placed near the seed with a potato-planter fitted with an end-delivery fertilizer mechanism (Cooke, Jackson and Widdowson²). A one-row drill fitted with a similar fertilizer mechanism (Cooke, *et al.*³), and driven by its own power unit, was used to place the superphosphate and sow the seed in experiments on swedes and fodder beet. The experiments on barley and fodder beet in 1953 and 1954 were carried out with a modified version of the one-row drill (Cooke, *et al.*³) which was drawn by cable winches operated by the power 'takes-offs' of two tractors. The fertilizer hoppers were covered with perspex screens to prevent the radioactive superphosphate being blown on to the operator. The drill was painted with a strippable lacquer (354-163), supplied by Imperial Chemical Industries, to which the fertilizer did not stick; most of the radioactivity was easily removed by washing.

Sampling and harvesting. The first sample taken from fodder beet in 1952 and 1953, and from swedes in 1952, consisted of the seedlings that were removed when the crop was singled. Later samples were taken from fodder beet, swedes and potatoes by removing corresponding leaves from all plants in each active row. Active and non-radioactive rows of potatoes, swedes and fodder beet were harvested separately and separate analyses were made of tops and roots in each year. Two samples of barley were taken before harvest in 1953, and one sample in 1954, by cutting the crop at ground level from measured lengths of the radioactive rows. All yields and total phosphorus uptakes are based on weights from the active plus inactive rows. Fertilizer uptake was derived from the weight and analysis of the active rows.

RESULTS OF THE EXPERIMENTS

Experiments on potatoes, fodder beet and swedes in 1952

The plots used in 1952 were too small and the distribution of the active superphosphate was too uneven to distinguish effects from different *forms* of broadcast fertilizers. Useful information was, however, obtained by comparing the mean effect of all broadcast phosphate fertilizers upon the percentage of radioactive superphosphate in the three crops at different stages of growth (Table III) and upon yield, total phosphorus uptake and the uptake of the active superphosphate at harvest (Table IV).

TABLE III

Percentage of total phosphorus in the crop derived from 10 lb. P per acre of placed radioactive superphosphate in the presence and absence of broadcast (non-radioactive) phosphate fertilizers. (Results from leaf samples, Highfield, 1952)					
Crop	Rate of application of broadcast (non-radioactive) phosphate fertilizers (lb. P per acre)	Percentage P derived from placed radioactive superphosphate			
		39 days from sowing	56 days from sowing	88 days from sowing	119 days from sowing
Potatoes	0.0	10	26	15	8
	22.5	15	22	8	6
Swedes	0.0	35	17	8	7
	22.5	37	15	8	6
Fodder beet	0.0	55	25	18	13
	22.5	44	18	14	10

The percentage of total phosphorus in the crops derived from the placed superphosphate by swedes and fodder beet decreased steadily with time. Broadcast applications of non-radioactive phosphates reduced this percentage at all sampling dates for fodder beet; the effects of the broadcast phosphates were less consistent with swedes (Table III). Results with potatoes were different as the percentage of labelled phosphorus in this crop increased between the 39th and 56th day after sowing and afterwards decreased until harvest. Except at the first sampling date, broadcast phosphate fertilizers also reduced the percentage of placed active phosphate in the potatoes. At harvest broadcast phosphate fertilizers increased yield and phosphorus uptake of potatoes and fodder beet, but not swedes

(Table IV). The percentage recoveries of the placed superphosphate, estimated from the P^{32} -content of the crops, were 7%, 18% and 36% for potatoes, swedes and fodder beet in the absence of broadcast phosphate fertilizers. Broadcasting non-radioactive phosphate fertilizers only slightly reduced the recovery of the placed superphosphate (Table IV).

TABLE IV

Yields of root crops, total phosphorus uptakes and uptakes from placed radioactive superphosphate applied at 10 lb. P per acre together with mean increases from broadcasting non-radioactive phosphates applied at 22.5 lb. P per acre. (Results at harvest, Highfield, 1952)						
Crop	Yield, roots (tons per acre)		Total phosphorus uptake (lb. P per acre)		Uptake of placed radioactive superphosphate (lb. P per acre)	
	No broadcast phosphate	Increase from broadcast	No broadcast phosphate	Increase from broadcast	No broadcast phosphate	Increase from broadcast
Potatoes	6.9	+2.1	8.2	+1.4	0.68	—0.04
Swedes	10.6	—0.1	23.2	—1.2	1.82	—0.40
Fodder beet	15.8	+1.8	27.5	+4.7	3.55	—0.14

Experiments on fodder beet in 1953 and 1954

The precision of the experiments on fodder beet in 1953 was increased by using larger plots and it was possible to compare the effects of different forms of broadcast phosphate fertilizers on the uptake of placed superphosphate by this crop. The results in Table V show that broadcast applications of superphosphate, dicalcium phosphate and Gafsa rock phosphate reduced the

TABLE V

Percentage of total phosphorus in fodder beet derived from 10 lb. P per acre of placed radioactive superphosphate in the presence and absence of different forms of broadcast (non-radioactive) phosphate fertilizers. (Results from leaf samples, Highfield, 1953)				
Form of broadcast (non-radioactive) phosphates	Rate of application (lb. P per acre)	Percentage P derived from placed radioactive superphosphate		
		58 days from sowing	90 days from sowing	131 days from sowing
None	0.0	55	28	23
Superphosphate	15.0	39	19	17
Superphosphate	30.0	33	14	13
Dicalcium phosphate	22.5	36	18	16
Gafsa rock phosphate	22.5	47	22	18

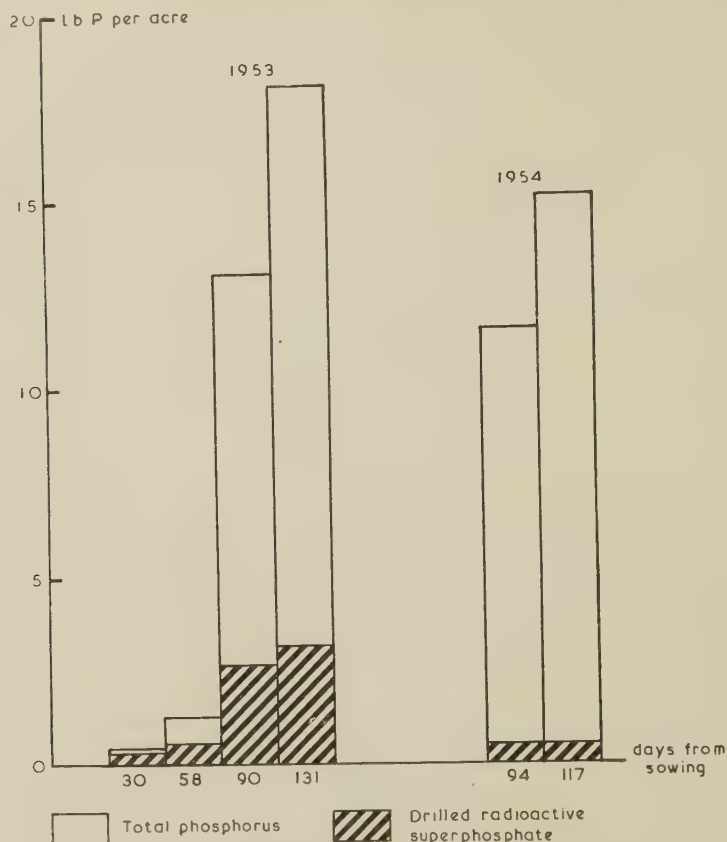


Fig. 1. Mean total phosphorus uptake, and mean uptake of drilled radioactive superphosphate by fodder beet at different stages of growth in 1953 and 1954.

percentage of phosphorus in fodder beet that was derived from placed superphosphate at each date of sampling. Differences between the percentage of labelled superphosphate in this crop due to broadcasting non-radioactive phosphates are used later to compare the efficiency of these fertilizers (Table VIII).

The mean uptakes of total phosphorus, and of phosphorus from the P^{32} -labelled superphosphate at different stages of growth, are shown in histograms in Figure 1; effects at harvest due to the simultaneous application of non-radioactive superphosphate (30 lb. P per acre) are given in Figure 2. The yields of roots and uptakes of total phosphorus were slightly increased by the application of

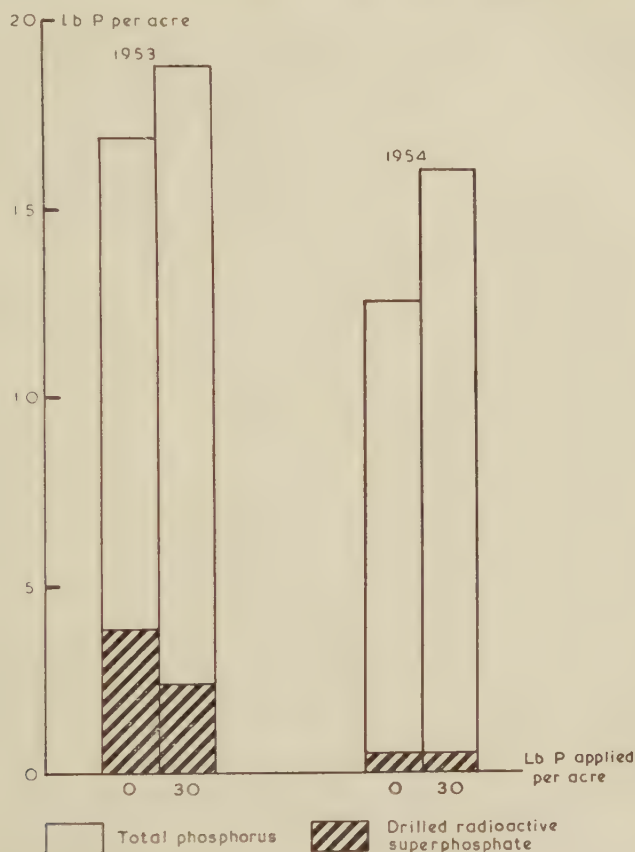


Fig. 2. Total phosphorus uptake and uptake of drilled radioactive superphosphate by fodder beet at harvest in 1953 and 1954, and effects of broadcasting non-radioactive superphosphate (30 lb. P per acre).

broadcast phosphate fertilizers in 1953. All broadcast phosphate fertilizers reduced the uptake of placed radioactive superphosphate at harvest (Table VI), the effect of 30 lb. P per acre applied as superphosphate being highly significant. The percentage recovery of placed superphosphate at harvest in the absence of broadcast phosphates was 38%, which is almost the same as in 1952.

In 1954 yields were lower and broadcast fertilizers did not affect either yield, total phosphorus uptake or the uptake of the placed superphosphate. As the growing season was only 94 days, compared with 119 days in 1952 and 131 days in 1953, plants from guard

TABLE VI

Yields of fodder beet, total phosphorus uptakes and uptakes of placed radioactive superphosphate applied at 10 lb. P per acre and increases at harvest from broadcasting non-radioactive phosphates							
	Year	No broadcast phosphate fertilizer	Increases from broadcasting non-radioactive phosphates				
			Super-phosphate (15 lb. P per acre)	Super-phosphate (30 lb. P per acre)	Dicalcium phosphate (22.5 lb. P per acre)	Gafsa rock phosphate (22.5 lb. P per acre)	Standard error
Yield, (tons per acre)	1953	11.6	+0.4	+0.9	+1.1*	+0.8	±0.47
	1954	3.3	0.0	+0.1	—0.1	+0.1	±0.21
Total phosphorus uptake, (lb. P per acre)	1953	16.9	+0.8	+1.9	+1.9	+1.3	±0.88
	1954	11.1	+0.6	+0.4	+0.3	+1.0	±1.03
Uptake of placed radioactive superphosphate, (lb. P per acre)	1953	3.83	—0.84	—1.46**	—0.84	—0.44	±0.415
	1954	0.51	+0.12	—0.07	+0.12	+0.08	±0.144

(Significant effects marked ** for $P < 0.01$; * for $P = 0.05$ to 0.01)

rows were harvested after a further 23 days. The yields of roots from the plots without broadcast phosphate fertilizers increased during this period by 4.0 tons per acre, and total phosphorus uptake, particularly on plots receiving the broadcast phosphate fertilizers, reached almost the same level as in 1953 (Figure 2). Uptakes from the placed superphosphate did not, however, increase and the percentage recovery (6%) 117 days after sowing was less than one-sixth of that in the previous year.

Experiments on barley in 1953 and 1954

In experiments of the same design with barley broadcast applications of superphosphate and dicalcium phosphate reduced, at all stages of growth, the percentage of phosphorus in the crop which was derived from the small dressing of drilled radioactive superphosphate. Rock phosphate, however, did not alter the percentage of radioactive superphosphate in the crop on Highfield (pH 7.4) and only slightly reduced it on Sawyers (pH 5.3). The percentages of drilled superphosphate in barley, which are not given, are used later (Table VIII) to discuss the effect of broadcast fertilizers on the labile phosphate content of the soils.

Yields at harvest, total phosphorus uptakes and uptakes of drilled superphosphate, (in the absence of broadcast phosphate fertilizers) together with the effects of broadcasting superphosphate, dicalcium phosphate or Gafsa rock phosphate are set out in Table VII. The uptakes of total phosphorus and of P^{32} -labelled superphosphate at different stages of growth in the experiments on Highfield and Sawyers in 1953 are given graphically in Figures 3

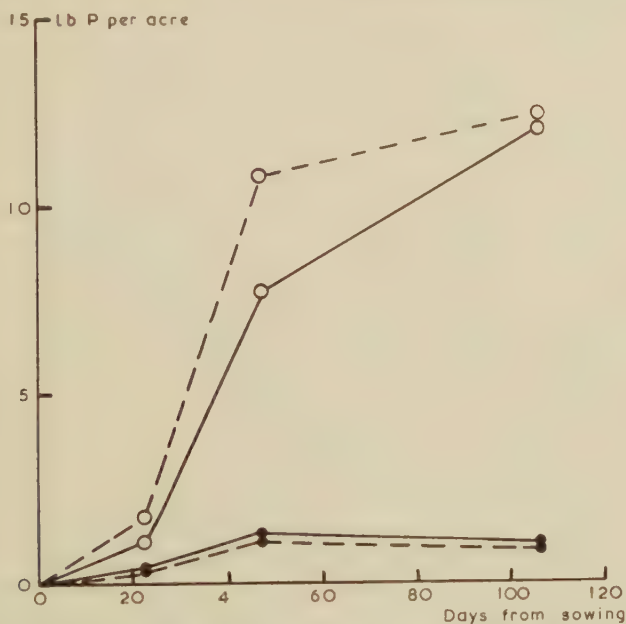


Fig. 3. Total phosphorus uptake and uptake of drilled radioactive superphosphate by barley on Highfield in 1953 and effects of broadcasting non-radioactive superphosphate (30 lb. P per acre).

- ○ — ○ — Total P uptake (no broadcast phosphate).
- ○ --- ○ --- Total P uptake (+ 30 lb. P per acre as non-radioactive superphosphate).
- ● — ● — Uptake of drilled radioactive P (no broadcast phosphate).
- ● --- ● --- Uptake of drilled radioactive P (+ 30 lb. P per acre as non-radioactive superphosphate).

and 4; the effects of broadcasting non-radioactive superphosphate (30 lb. P per acre) are shown in the same diagrams. Total phosphorus uptake was increased by broadcast superphosphate at all sampling dates before harvest. The uptake of drilled superphosphate in the

absence of broadcast phosphates increased with time, except on Highfield in 1953 where more was recovered (27%) in the crop 49 days after sowing than at harvest (21%). The total recovery of the drilled superphosphate on Highfield in 1954 (Table VII) was much less (10%) than in the previous year; the amounts recovered at harvest on Sawyers were almost the same (15% and 14%) in the

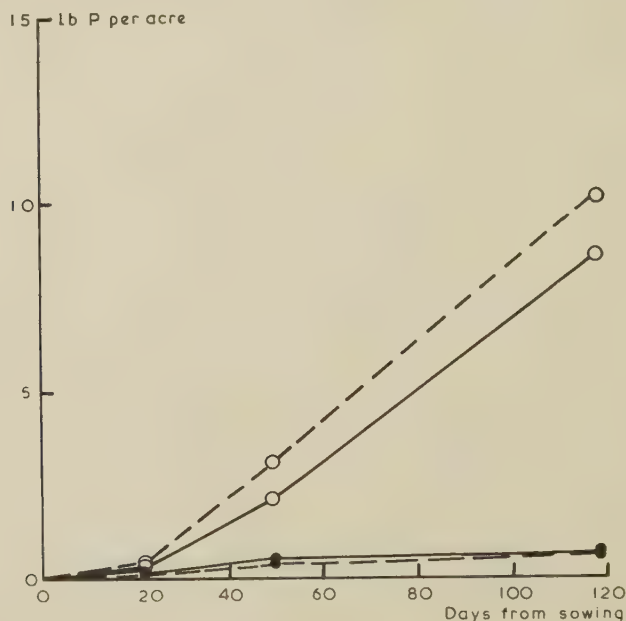


Fig. 4. Total phosphorus uptake and uptake of drilled radioactive superphosphate by barley on Sawyers in 1953, and effects of broadcasting non-radioactive superphosphate (30 lb. P per acre).

- ○ — ○ — Total P uptake (no broadcast phosphate).
- ○ --- ○ --- Total P uptake (+ 30 lb. P per acre as non-radioactive superphosphate).
- ● — ● — Uptake of drilled radioactive P (no broadcast phosphate).
- ● --- ● --- Uptake of drilled radioactive P (+ 30 lb. P per acre as non-radioactive superphosphate).

two years. The mean uptakes of P^{32} -labelled phosphate in the four experiments at harvest are shown graphically in Figure 5. It is clear that broadcasting amounts of non-radioactive superphosphate up to 30 lb. P per acre had practically no effect on the recovery of phosphate from the small drilled dressing of radioactive super-

TABLE VII

Yields of barley, total phosphorus uptakes and uptakes of drilled radioactive superphosphate applied lb. P per acre and the increases at harvest from broadcasting non-radioactive phosphates								
	Site of experiment	Year	No broadcast phosphate fertilizer	Increases from broadcasting non-radioactive phosphates				Standard error
				Super- phosphate (15 lb. P per acre)	Super- phosphate (30 lb. P per acre)	Dicalcium phosphate (22.5 lb. P per acre)	Gafsa rock phosphate (22.5 lb. P per acre)	
Yield, (cwt. dry grain per acre)	Highfield	1953	19.7	—0.6	0.0	+1.1	+1.0	±0.83
		1954	24.0	—0.4	—0.3	—1.8*	—0.6	±0.75
	Sawyers	1953	20.5	+1.7*	+3.5**	+2.5**	+1.2	±0.67
		1954	12.3	+7.5**	+7.8**	+7.0**	+0.5	±0.84
Total phosphorus uptake, (lb. P per acre in straw and grain)	Highfield	1953	12.0	+0.2	+0.4	+0.9	+0.8	±0.49
		1954	15.8	—0.6	—0.8	—0.4	—0.6	±0.72
	Sawyers	1953	8.6	+0.8*	+1.6**	+1.1**	+0.4	±0.29
		1954	4.9	+3.4**	+3.6**	+3.0**	+0.5	±0.46
Uptake of drilled radioactive fertilizer, (lb. P per acre in straw and grain)	Highfield	1953	1.06	—0.06	—0.15	—0.04	+0.17*	±0.074
		1954	0.49	—0.06	—0.08	—0.06	—0.10*	±0.037
	Sawyers	1953	0.74	+0.03	—0.07	+0.01	+0.04	±0.087
		1954	0.70	+0.10	—0.08	—0.06	+0.14	±0.101

(Significant effects marked ** for $P < 0.01$; * for $P = 0.05$ to 0.01)

phosphate. Dicalcium phosphate (22.5 lb. P per acre), which produced slightly lower yields of grain than an equivalent amount of superphosphate (Table VII) had, however, the same effect as superphosphate on total phosphorus uptake and on uptake of the drilled radioactive fertilizer (Figure 5).

DISCUSSION

Uptake of drilled and placed superphosphate by the crops

The low initial utilization of the placed phosphate by potatoes (Table III) is probably due to restricted root development as the maximum percentage of labelled phosphate was not reached until

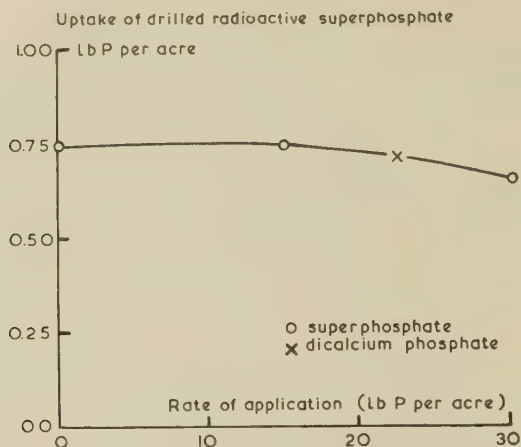


Fig. 5. Effect of rate of application of non-radioactive phosphate fertilizers on the uptake of drilled radioactive superphosphate by barley at harvest; mean results of 4 experiments.

about 56 days after planting. There were visual indications between 39 and 56 days after sowing that the crop was responding to the *broadcast* dressings of phosphate. The higher percentage of labelled phosphate in potatoes in the presence of broadcast fertilizers at the first sampling probably arises from the more rapid growth of the crop whereby the roots grow into the band of fertilizer. In 1952, the amount of labelled superphosphate drilled near the seed that was taken up by the root crops was approximately proportional to the total uptake of phosphorus, being greatest for fodder beet and least for potatoes (Table IV). The very low recovery of superphosphate by potatoes at harvest (7%) indicates that placement does not necessarily ensure this crop utilizes a large amount of the fertilizer. In American experiments the phosphorus taken up by potatoes from superphosphate was found to depend greatly on the level of soil phosphorus, and recoveries as low as 4% of the amount applied were obtained (Jacob, *et al.*⁷) on soils that had a high phosphate status.

The different percentage recoveries of drilled superphosphate by fodder beet in 1953 and 1954 (38% and 6%) and the differences in the effects of broadcast phosphates in the two years on the uptake of the placed superphosphate (Table VI), require explanation. Analytical data (Table I) show that the site on Highfield in 1954

had a higher total phosphorus content and a higher level of 'available phosphorus'. Crops grew slowly in the very cold and wet summer of 1954 and yields of beet were lower than in either 1952 or 1953. It is possible that, due to the slow rate of growth and higher level of phosphate in the soil, the root system developed extensively before the crop took up phosphate rapidly, and that consequently the superphosphate in the band placed near the seed was not used. As less than half as much phosphorus was also recovered by barley from the drilled superphosphate on Highfield in 1954 than in 1953 (Table VII), these results support those obtained on fodder beet. On Sawyers there was less difference in the rate of growth of barley in the two years, or in the phosphate status of the soils, and the absolute uptake of the drilled superphosphate was almost the same in 1953 and 1954.

In 1953 the amount of drilled superphosphate utilized on the old arable site (Sawyers) 49 days after sowing was 70% of the uptake at harvest, although the total phosphorus uptake at this stage was only 25% of the phosphorus in the straw and grain at harvest (Figure 4). The results on the site ploughed from pasture were unexpected. The amounts of drilled superphosphate in the crop 47 and 106 days after sowing were 1.4 and 1.0 lb. P per acre respectively (Figure 3); total phosphorus uptake increased from 7.8 to 12.0 lb. P per acre during this period. The smaller recovery of the drilled superphosphate at harvest is most unlikely to be due to sampling errors, as almost identical results were obtained in an adjacent (unpublished) experiment comparing placed and broadcast applications of radioactive superphosphate. The smaller uptake of drilled superphosphate at harvest could be explained either by the excretion through the roots of phosphate taken up early in growth or by older leaves, that contained a higher proportion of labelled phosphate than the surviving parts of the crop, dying off. The barley in 1953 was drilled in rows 6 in. apart and the crop was infected with powdery mildew (*Erysiphe graminis* DC) which caused the older leaves to fall. As Last^{8,9} has recently shown in experiments at Rothamsted that mildew infection can significantly reduce the yield of late-sown barley, the second explanation seems the more likely one. This conclusion is supported by results from a greenhouse trial which showed that the spores of powdery mildew infecting barley grown in the presence of P^{32} -labelled super-

phosphate had approximately the same specific activity as the host plant. It follows that the infected crops could lose both total and fertilizer phosphorus as dead leaves and by spore discharge.

The general conclusion from these experiments which were, however, restricted to two sites at Rothamsted, is that the amount of phosphorus taken up from superphosphate drilled near the seed of barley or root crops, is almost independent of the simultaneous application of normal agricultural dressings of phosphate fertilizers applied broadcast (Tables IV, VI and VII). The season and, therefore, the rate of growth of the crop, appeared to affect uptake more than the level of phosphate in the soil, less phosphate being taken up when the crop growth was slow.

Evaluation of broadcast phosphate fertilizers

In a previous short account of the use of P^{32} -labelled fertilizers to evaluate phosphate fertilizers in pot and field experiments (Mattingly and Widdowson ¹¹) 'superphosphate equivalents' of the fertilizers tested, derived from yield and phosphorus uptake, were compared with those obtained by measuring the decrease in the percentage of labelled phosphate in the crop due to non-radioactive fertilizers. Concordant results were obtained by the three methods for the evaluation of dicalcium phosphate and Gafsa rock phosphate in the two experiments on Sawyers. The effect of broadcasting dicalcium phosphate was discussed in the previous paper, in terms of the amount of *broadcast* superphosphate that produced the same yield, phosphorus uptake or percentage of labelled superphosphate in the crop. The method suggested by Fried ⁶ has been used here to calculate 'superphosphate equivalents' of all broadcast (non-radioactive) phosphates in terms of *placed* or *drilled* radioactive superphosphate as the standard. The labile phosphate in the soil and the mean increases resulting from broadcasting non-radioactive superphosphate or dicalcium phosphate are given in Table VIII.

The increase in labile phosphate at each sampling date was much less, measured by barley in 1953, than the amount of phosphate added in the broadcast dressings; in 1954 the increase was almost equal to the amount applied, particularly at harvest. For fodder beet, broadcast applications of superphosphate and dicalcium

TABLE VIII

Labile phosphate in soil (lb. P per acre) relative to drilled or placed p32-labelled superphosphate as a standard and increases at several stages of crop growth from broadcasting non-radioactive phosphates										
Crop	Site	Year	Days from sowing	No broadcast fertilizer	Increases from broadcasting non-radioactive phosphates				Mean increase from 22.5 lb. P per acre as superphosphate or dicalcium phosphate as a %age of amount of broadcast phosphate applied	
					Super-phosphate (15 lb. P per acre)	Super-phosphate (30 lb. P per acre)	Dicalcium phosphate (22.5 lb. P per acre)	Gafsa rock phosphate (22.5 lb. P per acre)		Standard error
Fodder beet	Highfield	1953	58	10.8	5.8*	10.1**	7.7**	1.6	2.40	35
			90	30.3	14.4*	33.1**	22.8**	10.0	6.52	104
			131	36.8	14.2*	33.2**	23.5*	11.9	7.96	105
Barley	Highfield	1953	22	6.8	2.2	9.7**	6.5**	1.0	1.68	27
			47	24.1	3.4	20.8**	11.4**	1.8	3.60	53
			106	54.8	1.5	13.7**	8.2	—4.1	5.76	35
Barley	Sawyers	1953	22	7.4	1.8	7.9*	5.8	0.3	2.83	23
			49	16.5	3.8	27.0**	11.3	2.9	6.86	62
			118	48.8	1.8	18.9	13.5	1.2	9.54	51
Barley	Highfield	1954	49	84.2	6.0	20.6	17.2	10.0	28.14	65
			116	157.6	23.2	31.9	19.8	[57.5] ^a	24.54	111
Barley	Sawyers	1954	40	3.4	13.8*	33.8**	19.4**	0.2	4.52	99
			104	28.4	19.2**	38.1**	27.0**	2.1	5.90	125

 (Significant effects marked ** for $P = 0.01$; * for $P = 0.05$ to 0.01), (a) Anomalously high

phosphate increased the labile phosphate in the soil 58 days after sowing by only 35% of the amount applied; after 90 and 131 days, however, the increase corresponded very closely with the amounts of phosphate applied broadcast. The increase in labile phosphate, relative to a drilled application of radioactive superphosphate, should give at least a qualitative measure of the superiority of placement over broadcasting. In contrast to previous results (Mattingly and Widdowson¹¹), no direct comparison is possible in these experiments between yields from drilled and broadcast applications of superphosphate and the increases in labile phosphate in soil which they produce. The apparent superiority of drilled over broadcast dressings for barley in 1953 agrees, however, with the extensive experiments described by Crowther⁴. For fodder beet the approximate equivalence of broadcast and placed applications of superphosphate at harvest, which is indicated by these results, also agrees with experiments by Cooke¹, who concluded that placement of superphosphate and potash together in bands near the seed was not more effective for sugar beet than broadcasting.

These experiments have established that it is possible to measure quantitatively in the field the increase in labile phosphate in the soil resulting from the addition of single dressings of dicalcium phosphate or superphosphate at rates commonly applied in practice. Further experiments would be necessary to compare critically the increase in labile phosphate in soil produced by broadcast phosphate fertilizers with yield response from broadcast and drilled superphosphate in the same experiment. A single experiment of this type, carried out in 1955, showed reasonable agreement between the evaluation of fertilizer placement by the two methods.

SUMMARY

1. Nine field experiments using radioactive superphosphate on two contrasting soils at Rothamsted are described. In five experiments on root crops P^{32} -labelled superphosphate supplying 10 lb. P per acre was drilled 2 in. below soil level and 2 in. to the side of the seed; in four experiments on barley, radioactive superphosphate (5 lb. P per acre) was drilled in contact with the seed. The effects of the simultaneous application of non-radioactive fertilizers (superphosphate, dicalcium phosphate and Gafsa rock phosphate) on yield, total phosphorus uptake and uptake of the drilled superphosphate

were investigated. The influence of soil conditions and weather on phosphorus uptake are discussed briefly and results from the experiments are used to compare broadcast fertilizers relative to drilled superphosphate as a standard.

2. The recoveries of placed superphosphate by potatoes, swedes and fodder beet in 1952, in the absence of broadcast phosphate fertilizers were 7%, 18% and 36% respectively of the amount applied. Percentage recoveries of the placed superphosphate by fodder beet in 1953 and 1954 were 38% and 6%. The amount of superphosphate drilled with the seed that was taken up by barley varied with the site at which the experiments were carried out and increased (with one exception) with time from sowing. The mean recoveries at harvest in 1953 and 1954 were 21% and 10% on a site recently ploughed up from old pasture, and 15% and 14% on an arable site. Recovery of the placed superphosphate by fodder beet was reduced from 38% to 31% in 1953 in the presence of broadcast phosphates. The amount of the placed superphosphate taken up by fodder beet on the same site in 1954 was 6% of the total phosphate applied; broadcasting non-radioactive superphosphate did not alter the percentage recovery.

3. Broadcasting non-radioactive superphosphate or dicalcium phosphate only increased the yield and total phosphorus uptake of barley significantly at harvest on the old arable soil. The effects from Gafsa rock phosphate were very small. Percentage recovery of drilled superphosphate by barley at harvest was only slightly reduced by broadcasting amounts of superphosphate or dicalcium phosphate up to 30 lb. P per acre. The uptake of phosphorus from superphosphate drilled near the seed of barley or root crops depended more on the season and soil than on the simultaneous application of other phosphate fertilizers.

4. The increase in the labile phosphorus in the soil from broadcasting non-radioactive phosphate fertilizers was measured relative to drilled P^{32} -labelled superphosphate as a standard. The increase in labile phosphorus varied with the crop, the stage of growth and the year of the experiments. The mean increase in labile phosphate, measured by fodder beet, in the soil as a result of broadcasting superphosphate or dicalcium phosphate in 1953 was 35% of the amount of phosphate applied 58 days after sowing and about 100% at harvest. Increases in labile phosphate measured by barley in 1953 were less than the amounts applied; in 1954 the increases were equal to or slightly greater than the total quantity of broadcast phosphate. The possible significance of these values, and their application to evaluating phosphate fertilizers in field experiments is discussed.

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